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DYNAMIC WALL DEMONSTRATION PROJECT

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DYNAMIC WALL DEMONSTRATION PROJECT

December 1990

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The views and conclusions expressed and the recommendations made in this report are entirely those of the authors and should not be construed as expressing the opinions of Alberta Municipal Affairs.

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FOREWORD

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TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY viii

1.0 INTRODUCTION 1

2.0 OBJECTIVES 4

3.0 METHOD 5

3.1 The Dynamic Wall Demonstration House 5

3.1.1 General Description of the Demonstration House 5
3.1.2 Construction Specifications 5
3.1.3 The Envelope 14
3.1.3.1 Envelope Construction Details 17
3.1.3.2 Envelope Airtightness 24
3.1.4 Fibreboard Test Panel 25
3.1.5 House Systems 25
3.1.5.1 Heating and Ventilation 25
3.1.5.2 Hot Water Heating 28
3.1.5.3 Electrical System 28
3.1.6 Other Details 29
3.1.7 Costs 29

3.2 Testing for Confirmation of Operation 29

3.3 Long-Term Operational Monitoring 30
3.3.1 Monitoring and Sensing Equipment 30
3.3.2 Computer-Measured Parameters 31
3.3.3 Measurement of Indoor Air Quality 34
3.3.3.1 Passive Air Change Tests 34
3.3.3.2 Radon 34
3.3.3.3 Formaldehyde 34
3.3.3.4 Glass Fibre 35
3.3.4 Homeowner Comfort 35

3.4 Monitoring Schedule and Data 35

Page

4.0 FINDINGS 38

4.1 Temperature Profile of the Envelope 38
- 4.1.1 Kitchen-Family Room Area 38
- 4.1.2 Living Room 38
- 4.1.3 Windows 39
- 4.1.4 Basement 39
- 4.1.5 Northwest Bedroom Floor (over garage) 39
- 4.1.6 Static vs. Dynamic Operation 39

4.2 Dynamic Airflow Rate 40
- 4.2.1 Airtightness of the Envelope 40
- 4.2.2 Dynamic Air Flows 40
- 4.2.3 Optimum Dynamic Airflow Velocity 44
- 4.2.4 Actual Dynamic Air Flows 44

4.3 Building Envelope Pressures 45
- 4.3.1 Effects of Different Exhaust Flow Rates on Building Envelope Pressures 45
- 4.3.2 Effects of Wind Speed and Direction on Building Envelope Pressures 48
- 4.3.3 Effects of Varying Pressures on Indoor Air Quality 58

4.4 Dynamic Air Temperatures 58
- 4.4.1 Building Envelope Temperature Profile 58
- 4.4.2 Comparison with Fibreboard Cavity 65
- 4.4.3 Dynamic Air Thermal Characteristics 65
- 4.4.4 Effects of Wind Speed and Direction on Dynamic Air Temperatures 69
- 4.4.5 Effects of Solar Radiation 72

4.5 Indoor Air Quality 78
- 4.5.1 Actual Air Change Rates 78
- 4.5.2 Radon 78
- 4.5.3 Formaldehyde 79
- 4.5.4 Glass Fibres 79

Digitized by the Internet Archive
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https://archive.org/details/dynamicwalldemon00naka

Page

4.6 Homeowner Comfort 79

4.7 Incremental Cost Estimates 81
    4.7.1 Incremental Costs of the Demonstration House as Constructed 81
    4.7.2 Energy Performance of the Demonstration House 83

5.0 CONCLUSIONS 85

6.0 RECOMMENDATIONS FOR FUTURE STUDY 87

6.1 Technical Considerations 87

6.2 Practical Considerations 88

6.3 Potential Reductions in Incremental Costs 89

LIST OF APPENDICES

A Blower Door Air Test Reports A1-A4

B Analysis of Air Flows Based on Blower Door Tests B1-B3

C Daily Averaged Envelope Pressure Differentials C1-C5

D Daily Averaged Dynamic Air Temperatures D1-D5

E Average Temperature Differential Across Dynamic Wall E1-E5

F Cost Comparison for Demonstration House and R-2000 Standard House F1-F6

G Potential Alternative Sheathing Configurations for the Dynamic Wall System G1-G4

REFERENCES

LIST OF TABLES

Page

1 Summary of Construction Specifications 15
2 Computer-Measured Parameters and Sensors 32
3 Building Envelope Pressures 47
4 Effect of Wind on Dynamic Air Flow 50
5 Average Pressure Differentials Between Floors 51
6 South Wall Temperature Profile 61
7 Decrease in Drywall Surface Temperature 62
8 Comparison of Glasclad and Fibreboard Cavities 66
9 Dynamic Air Temperature Differentials 68
10 Formaldehyde Readings 80
11 Summary of Incremental Costs 82

LIST OF PHOTOGRAPHS

1 Demonstration House Prior to Siding 6
2 Taping at Corners, Penetrations, Windows 6
3 Temperature/Pressure Sensors Roughed In 7
4 Fibreboard Test Panel 26

LIST OF FIGURES

		Page
ES-1		ix
1	House Elevations (Front and West Side)	8
2	House Elevations (Rear and East Side)	9
3	Main Floor Plan	10
4	Second Floor Plan	11
5	Basement Plan	12
6	House Cross-Section	13
7	Typical Wall Section	18
8	Cross Section of Baseboard Detail	19
9	Front View of Baseboard Detail	19
10	House-Garage Interface	20
11	Gable End Detail	21
12	Exterior Corner Detail	22
13	Window Opening Detail	23
14	Mechanical System Schematic	27
15	Dynamic Air Flows: Main Floor	42
16	Dynamic Air Flows: Second Floor	43
17	Envelope Pressure Differentials - 2nd Floor	52
18	Envelope Pressure Differentials - Main Floor	53
19	Envelope Pressure Differentials - 2nd Floor	55
20	Envelope Pressure Differentials - Main Floor	56
21	Envelope Pressure Differentials - 2nd Floor	57
22	Envelope Pressure Differentials - Main Floor	59
23	South Wall Temperature Profile	64
24	Effect of Pressure on Dynamic Wall Temperature	70
25	Effect of Pressure on Dynamic Wall Temperature	71
26	Sol-Air Effect - Cold Day	73
27	Sol-Air Effect - Warm Day	74
28	Sol-Air Effect on All Four Walls	75
29	Sol-Air Effect on Dynamic Air Temperature	76
30	Sol-Air Effect on Dynamic Air Temperature	77

EXECUTIVE SUMMARY

The dynamic wall concept is a ventilation strategy that can be applied to single family dwellings. With suitable construction, outside air can be admitted through the exterior walls of the house to the interior space to function as ventilation air. Figure ES-1 shows the basic construction details and the mechanics of operation of the dynamic wall.

This report describes the construction and performance monitoring of a demonstration house built to test the dynamic wall concept in Sherwood Park, Alberta. The project had the following objectives:

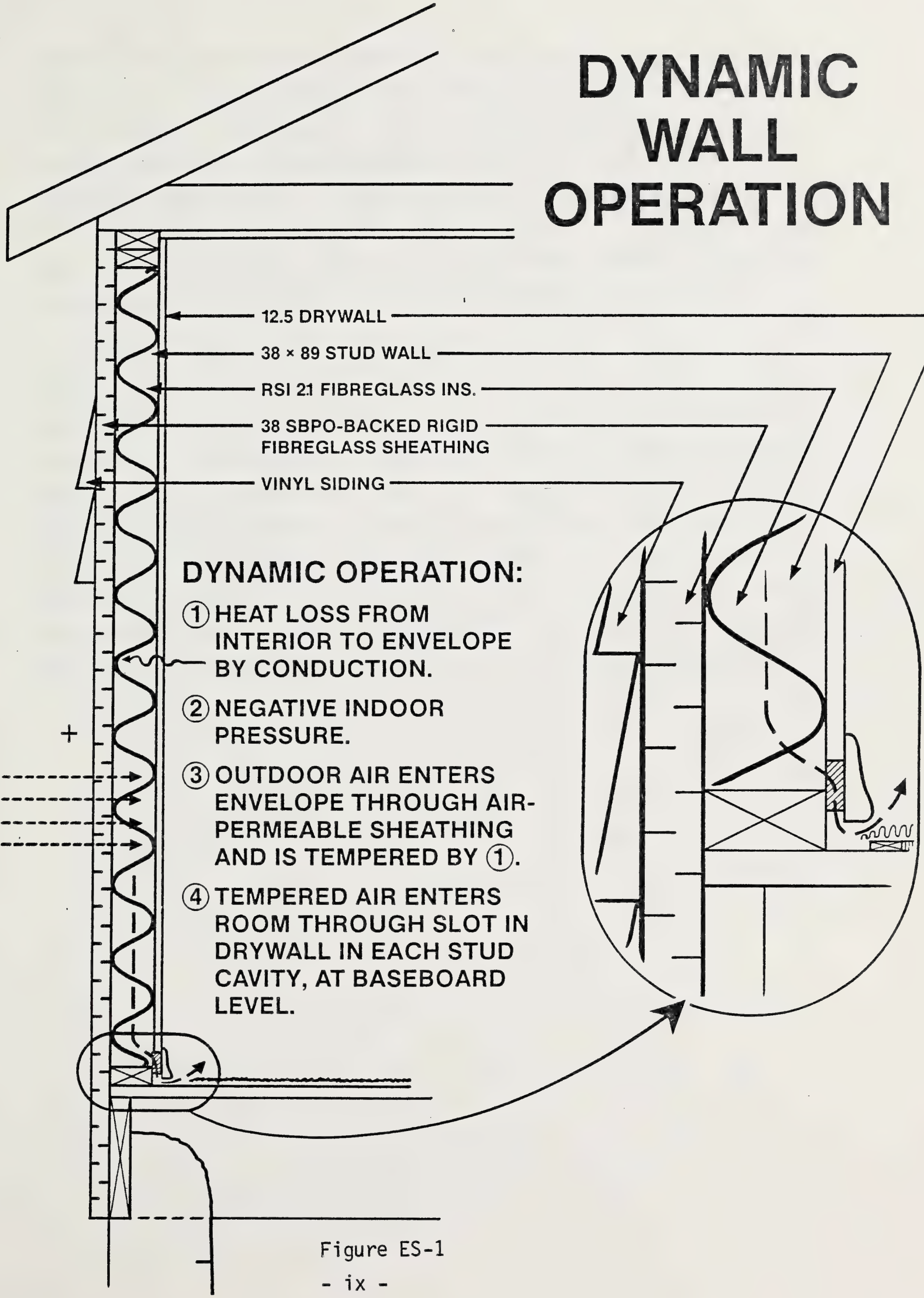
(1) To demonstrate and assess the construction methods
(2) To determine the cost-effectiveness of the concept in Alberta
(3) To analyze the operation of the dynamic wall system
(4) To determine how other components and systems in the house interact with the dynamic wall

The demonstration house was built in the winter of 1988-89. Exterior wall construction consisted of vinyl siding, spun-bonded polyolefin-backed (SBPO) rigid fiberglass sheathing, 38 mm x 89 mm framing, fiberglass batt insulation, and 12.7 mm drywall. The mechanical system was designed to operate in the dynamic (negative pressure) mode. However, flexibility was provided to allow operation in the static (balanced pressure) mode as well to permit monitoring of the walls as if they were in a conventional house.

Following construction, the demonstration house was monitored by an extensive computerized monitoring system during the 1989-90 heating season to determine whether the dynamic wall system would perform according to theory, and whether the homeowner would benefit in terms of space heating, air quality, and comfort.

The incremental cost of building the demonstration house was approximately $4,200.00 more than a conventional house of similar size. Annual energy costs were estimated as $370.00 less.

DYNAMIC WALL OPERATION



DYNAMIC OPERATION:

① HEAT LOSS FROM INTERIOR TO ENVELOPE BY CONDUCTION.

② NEGATIVE INDOOR PRESSURE.

③ OUTDOOR AIR ENTERS ENVELOPE THROUGH AIR-PERMEABLE SHEATHING AND IS TEMPERED BY ①.

④ TEMPERED AIR ENTERS ROOM THROUGH SLOT IN DRYWALL IN EACH STUD CAVITY, AT BASEBOARD LEVEL.

Figure ES-1

Dynamic wall operation was dependent upon pressure and temperature differentials between indoors and outdoors as well as wind speed and wind direction. The degree of tempering (heat gain) of dynamic airwas found to be approximately 74% of the indoor-outdoor temperature differential. The temperature of incoming dynamic air was significantly affected by solar radiation. Measurements of indoor air pollutants showed no significant levels, and the occupants found the dynamic wall house comfortable to live in.

The dynamic wall concept was found to be both achievable and, despite the uncontrollable variables, operable in the Alberta environment. Further research could significantly improve the cost-benefit relationship. Exterior sheathing comprised roughly one-half of the incremental cost, so substantial gains could be realized if less expensive sheathing equivalents were identified. Further cost reductions may be possible by simplifying the mechanical system and the entry method for dynamic air. Further research may lead to the means to benefit from the solar radiation and increase the degree of tempering of the incoming dynamic air.

1.0 INTRODUCTION

The house building industry is under continuing pressure to provide affordable energy-efficient housing without sacrificing quality. The recognition of indoor air pollution as a health hazard is increasing the pressure.

The Canadian Home Builders' Association administers the R-2000 Program, which defines a means for building super energy-efficient houses. Although attainment of the program's air quality and energy targets tends to increase the cost of houses, the housing industry has found ways to reduce the incremental costs associated with the early R-2000 homes. Builders have found that super thick double wall systems are not necessary. The "Airtight Drywall Approach" (ADA), which uses drywall, lumber, and strategically placed gaskets as the air barrier system has improved the builders' ability to meet the airtightness standard of the R-2000 Program with walls of standard thickness.

Improved airtightness has resulted in requirements for mechanically assisted combustion air systems and mechanical ventilation systems. Consumers are beginning to accept the higher costs of tighter building envelopes and are somewhat reluctantly accepting the associated incremental costs for non-naturally-aspirated, gas-fired appliances. But in Alberta, particularly, consumers do not readily accept the high costs of heat recovery ventilators nor the high operating costs resulting from mechanical ventilation without heat recovery. A ventilation strategy that is effective, reliable, and relatively inexpensive is essential for consumer acceptance of an energy-efficient house.

The Dynamic Wall Theory is a ventilation strategy with the potential to meet these criteria. The theory was conceived in Sweden (Anderlind & Johansson 1983), but it was Dr. John Timusk at the University of Toronto who worked on the practical application of the theory in Canada by means of laboratory work and a demonstration house (referred to in this report as "the Timusk house").

The construction details of a dynamic wall house ensure that the house is sufficiently airtight to direct incoming ventilation air through the "dynamic" portion of the building envelope, that is, the portion built sufficiently air-permeable to allow air to be drawn in at very low velocity. Incoming (exterior) ventilation air enters the interior living space through dynamic air inlets (holes drilled or cut in the drywall) near the base of each exterior wall stud cavity. The loss of heat by the interior air to the envelope by conduction creates a temperature gradient across the envelope. The temperature of the incoming air rises because of this temperature gradient. Optimally, the temperature profile of the wall is not affected by this process.

A properly functioning dynamic wall may provide the following advantages:

(1) Acceptability of relatively thin walls, which perform as if they are thicker, thus resulting in both a saving of energy and an increase in interior space. Decreasing the wall thickness in a 2,000 sq. ft. house by one inch increases the floor area by some 20 sq. ft.

(2) The provision of ventilation air with a lower potential for mechanical failure and without the costs associated with typical heat recovery ventilators. Reduced noise, reduced drafts, and reduced electrical consumption costs could increase the likelihood that homeowners will operate their ventilation systems continuously.

(3) Effective distribution of ventilation air without any additional ductwork, making it an ideal system for non-forced-air-heated houses.

(4) Virtual elimination of the potential for interstitial wall moisture problems by the action of negative pressure and the resultant inflow of air from the outside.

(5) The potential to capture significant amounts of solar energy at no additional cost. With the use of a heat pump, even more energy could be captured from the stale air exhaust stream.

A tract-built demonstration house was built near Edmonton by Residential Construction Group Inc. to test the Dynamic Wall Theory and assess the applicability of the dynamic wall concept to production housing in Alberta. The Edmonton house has some complexities (such as the adjoining garage) that did not exist in the Timusk house, but both are four-bedroom, two-storey houses.

This report describes the study of the dynamic wall concept. Section 2.0 lists the objectives of the study. Section 3.0 describes the construction details of the demonstration house and the subsequent testing and monitoring of the house. Section 4.0 presents the findings and discusses the incremental construction costs for a dynamic wall house, and Section 5.0 presents the conclusions.

Recommendations for future study that were formulated during consideration of the findings are presented in Section 6.0.

2.0 OBJECTIVES

The project to construct and test the dynamic wall demonstration house had the following objectives:

(1) To demonstrate and assess the construction details required for operation of the dynamic wall

(2) To determine the applicability and cost-effectiveness of the dynamic wall system for production housing in Alberta

(3) To analyze the operation of the dynamic wall system with respect to the following:

- The effectiveness of the dynamic wall in preheating ventilation air at various outdoor temperatures, especially cold temperatures
- The performance of the dynamic wall at various air exchange rates
- The effect of the system on indoor air quality and occupant comfort
- The effects of solar radiation, wind speed and wind direction on the performance of the dynamic wall
- The differences in operation and performance of the house with the exterior walls operating in the static and dynamic modes

(4) To determine how other components and systems in the house interact with the dynamic wall

3.0 METHOD

3.1 THE DYNAMIC WALL DEMONSTRATION HOUSE

3.1.1 General Description of the Demonstration House

The demonstration house was constructed in Sherwood Park, a community approximately 20 km east of Edmonton. Situated in central Alberta, 250 km east of the Rocky Mountains at the western edge of the prairie region, Edmonton is located at 53°N latitude and 113°W longitude, at an elevation of 676 m.

In general, the province of Alberta has a continental climate with 2000 to 2200 hours of sunshine per year, more than any other Canadian province. Winters are cold, sunny and dry; summers are warm and sunny, but wetter. Annual precipitation averages 45 cm.

The demonstration house was constructed during the winter of 1988-89 in the northeast quadrant of the Craigavon Subdivision. The house is located on the south side of a street that runs east and west. The surrounding subdivision is almost fully built up with no vacant lots adjacent to the house.

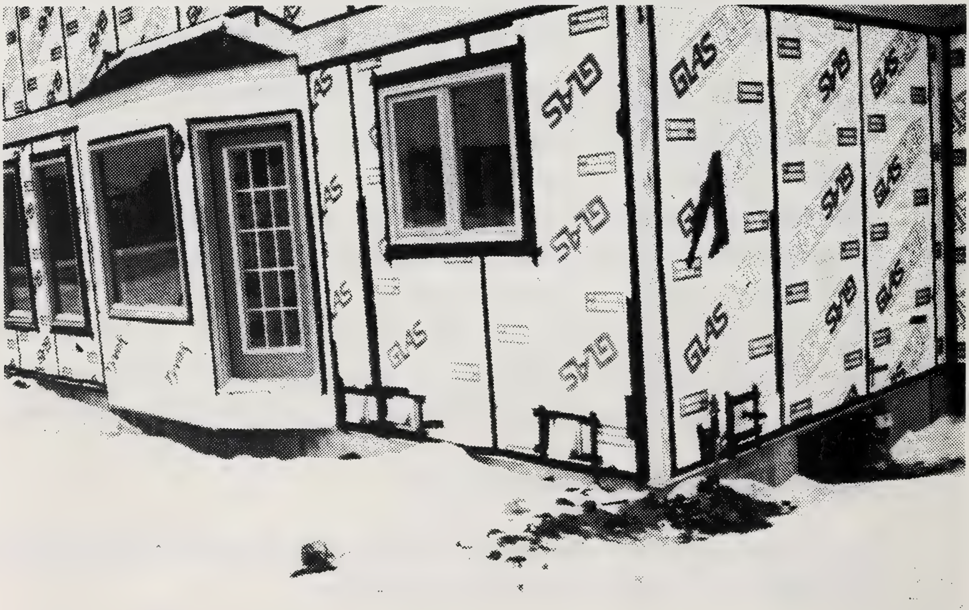
It is a typical four-bedroom, two-storey house with an attached two-car garage (Photographs 1 to 3 and Figures 1 to 6). The main floor includes a living room at the front of the house (with windows facing north), a dining room with a west exposure, a laundry room with an east exposure, and the kitchen, eating nook, and family room all on the rear (with windows facing south). Thus the highest percentage of the main floor glazing faces south. The upper floor has two bedrooms on the rear (with windows facing south), and two bedrooms on the front (with windows facing north).

3.1.2 Construction Specifications

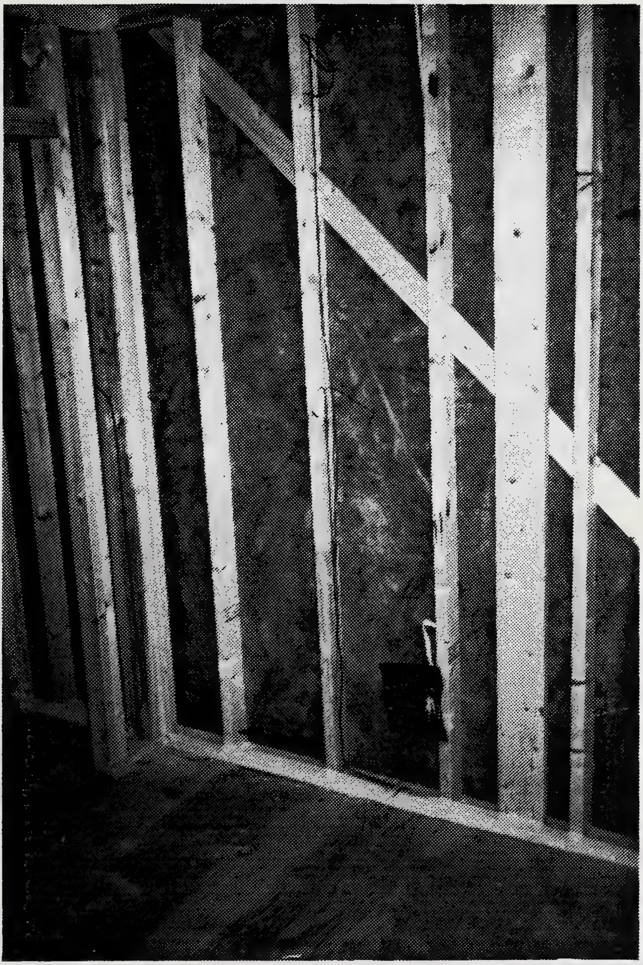
The house generally conforms to conventional wood-frame standards in Alberta with the following exceptions:

- Glasclad (Tyvek-backed rigid glass fibre) sheathing was used

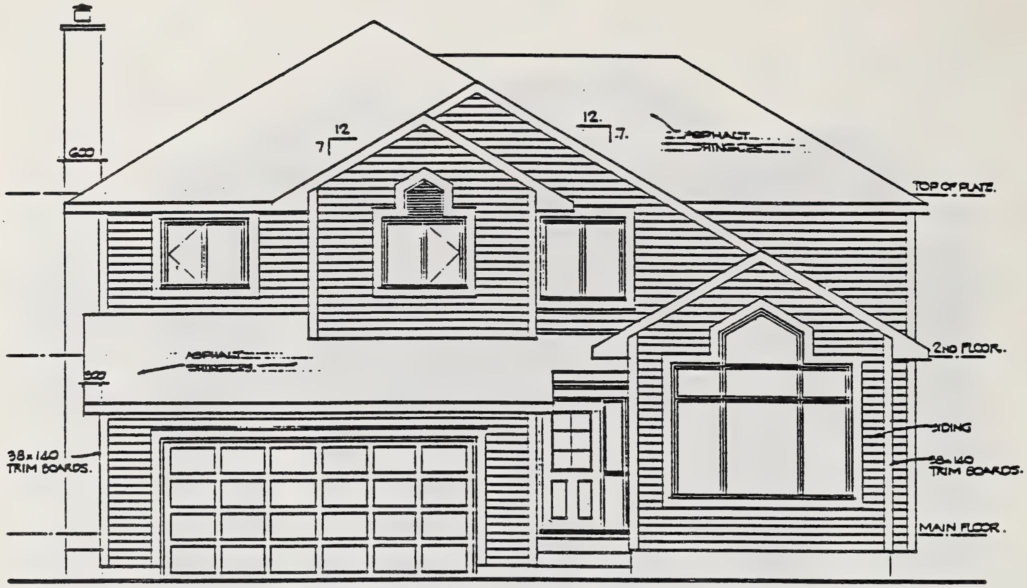
Photograph 1: Demonstration House Prior to Siding



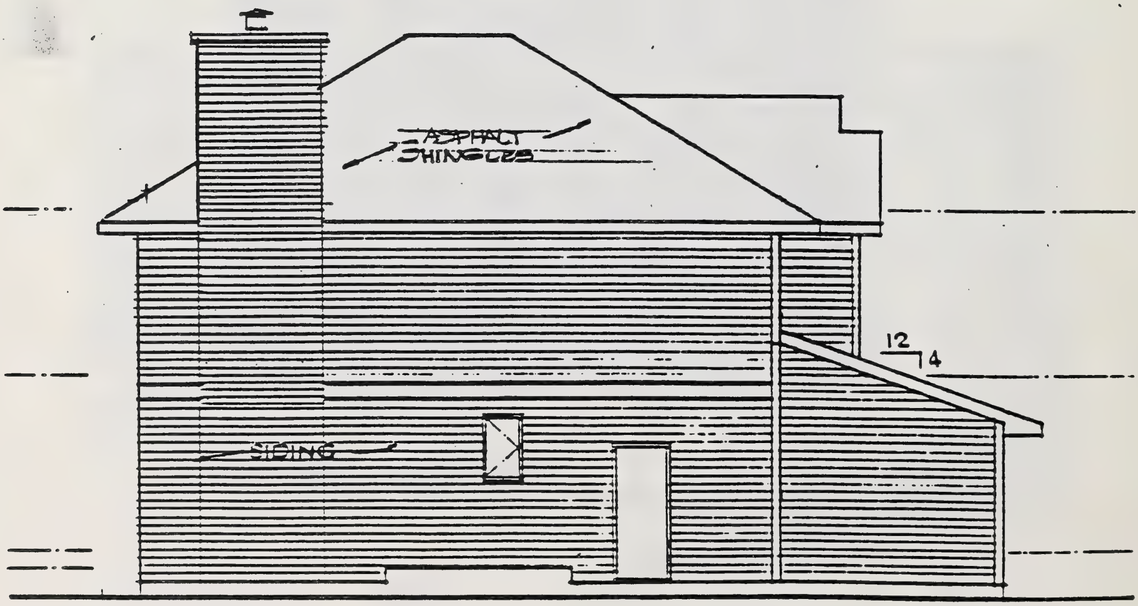
Photograph 2: Taping at Corners, Penetrations, Windows



Photograph 3: Temperature/Pressure Sensors Roughed In

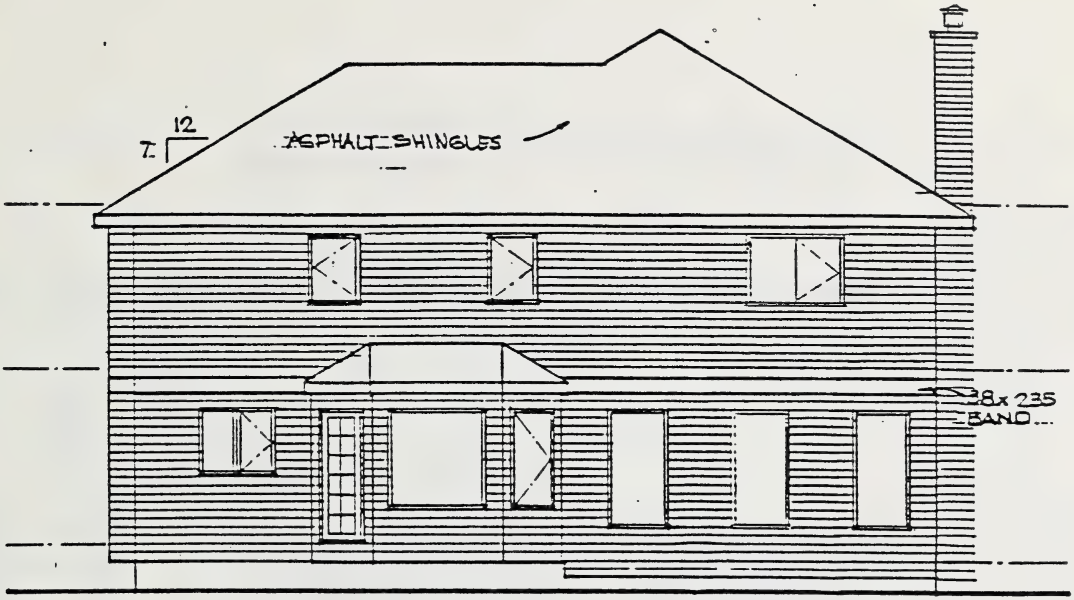


NORTH ELEVATION.

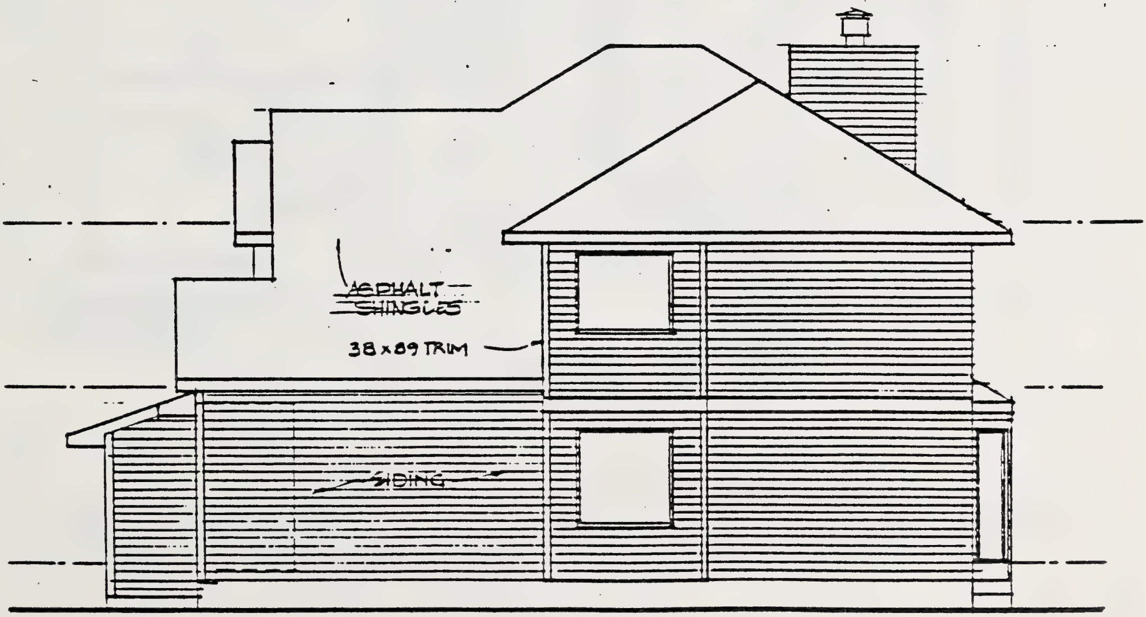


WEST ELEVATION.

Figure 1: House Elevations (Front and West Side)



SOUTH ELEVATION



EAST ELEVATION

Figure 2: House Elevations (Rear and East Side)

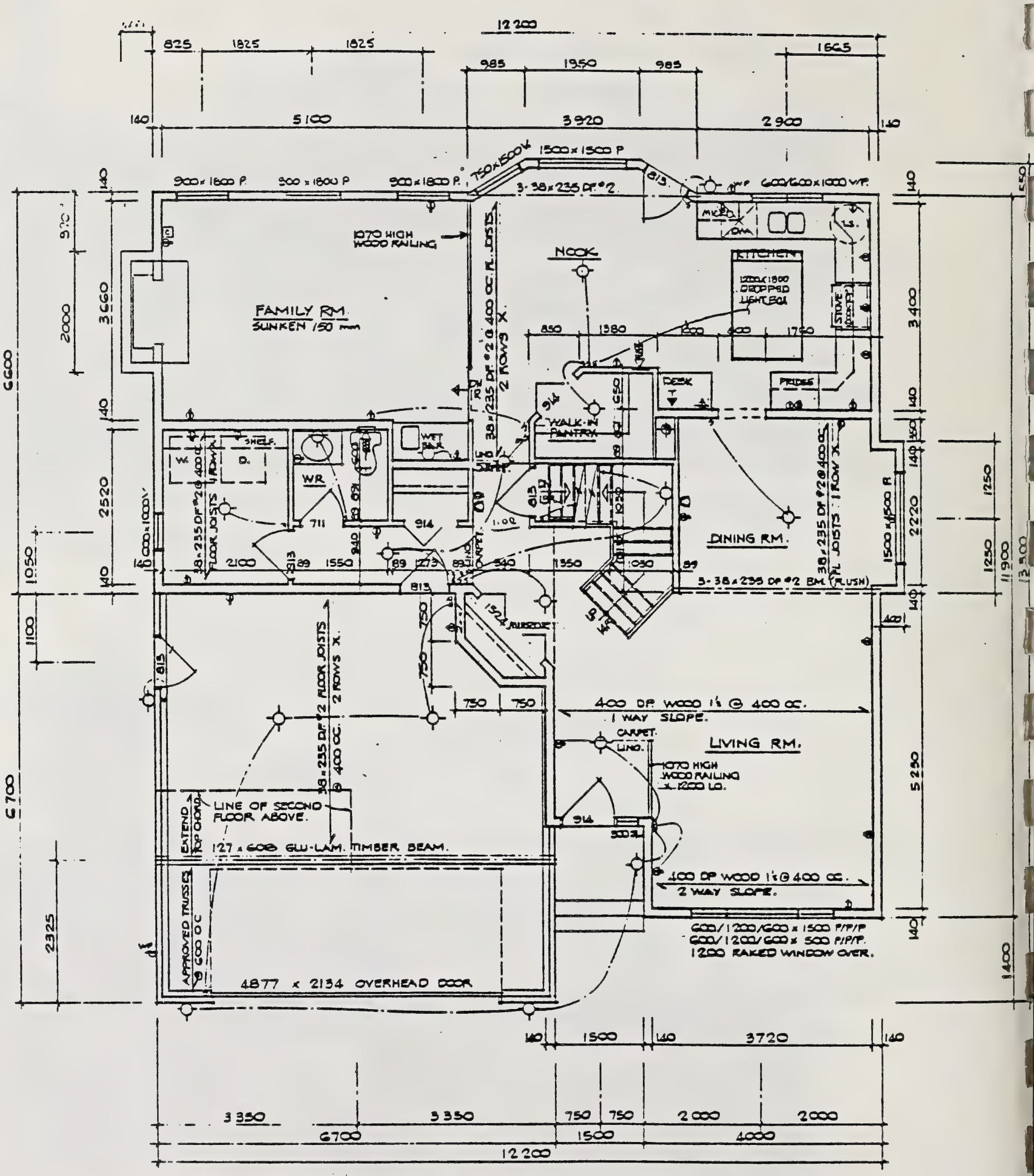


Figure 3: Main Floor Plan

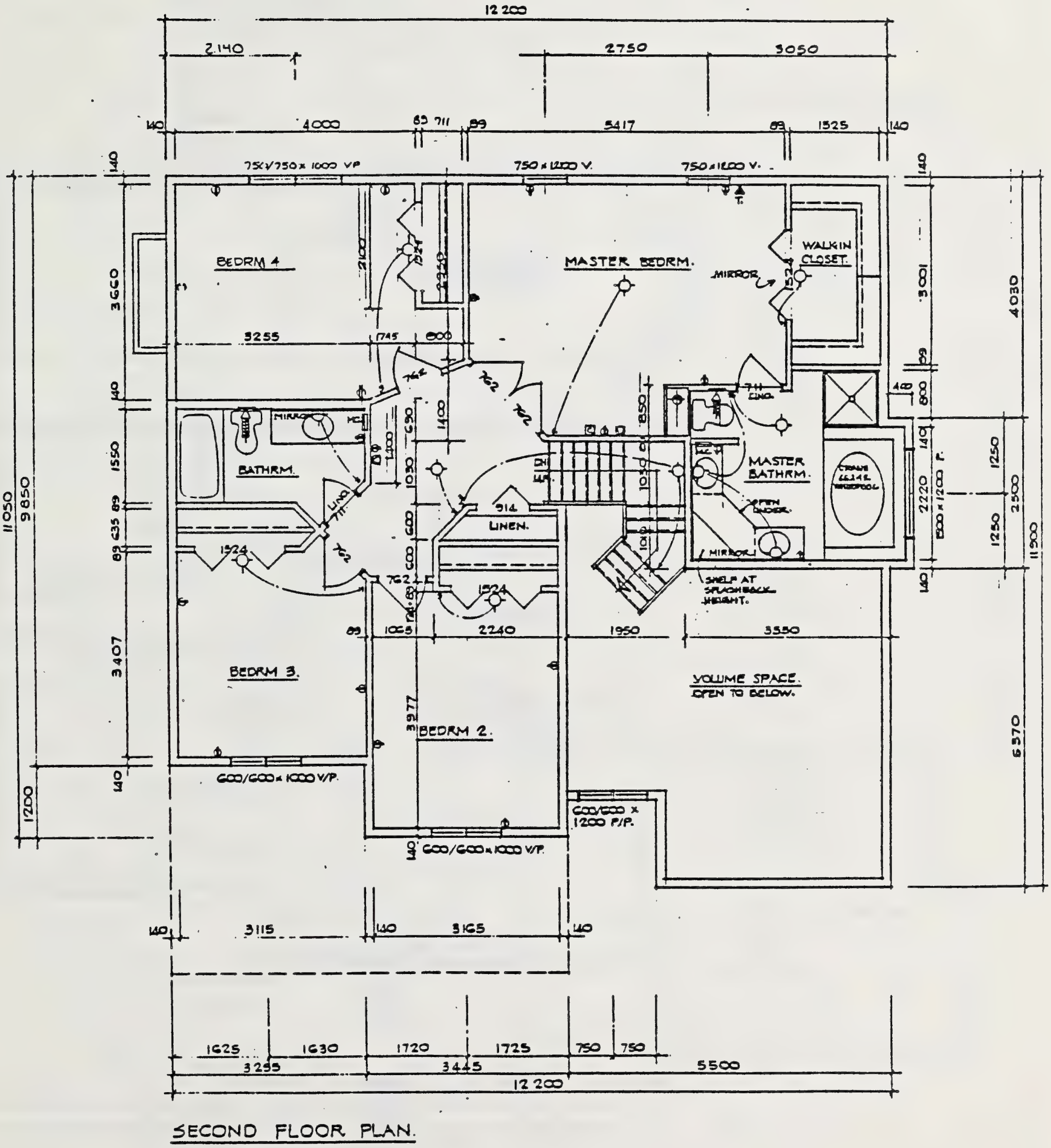


Figure 4: Second Floor Plan

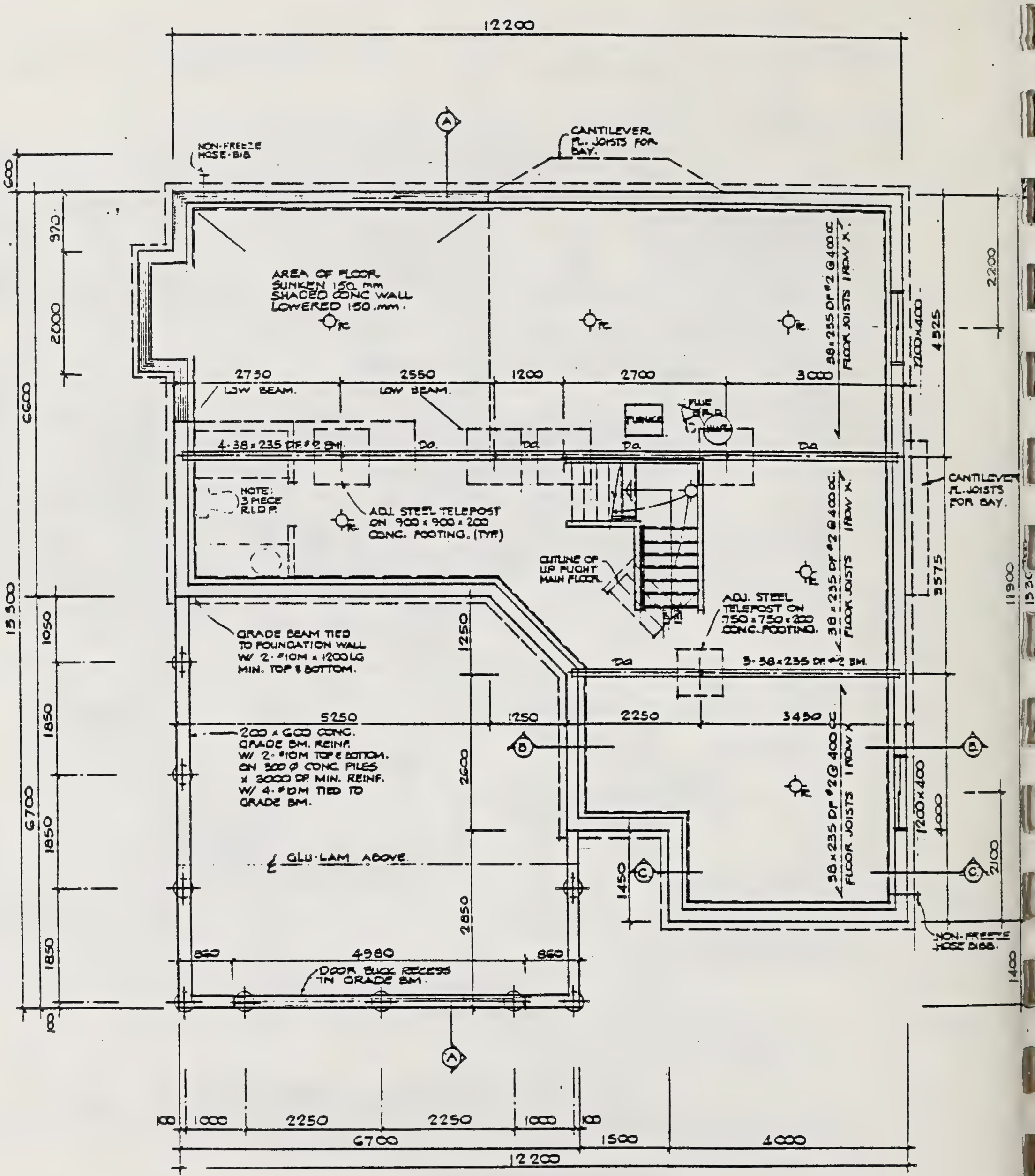
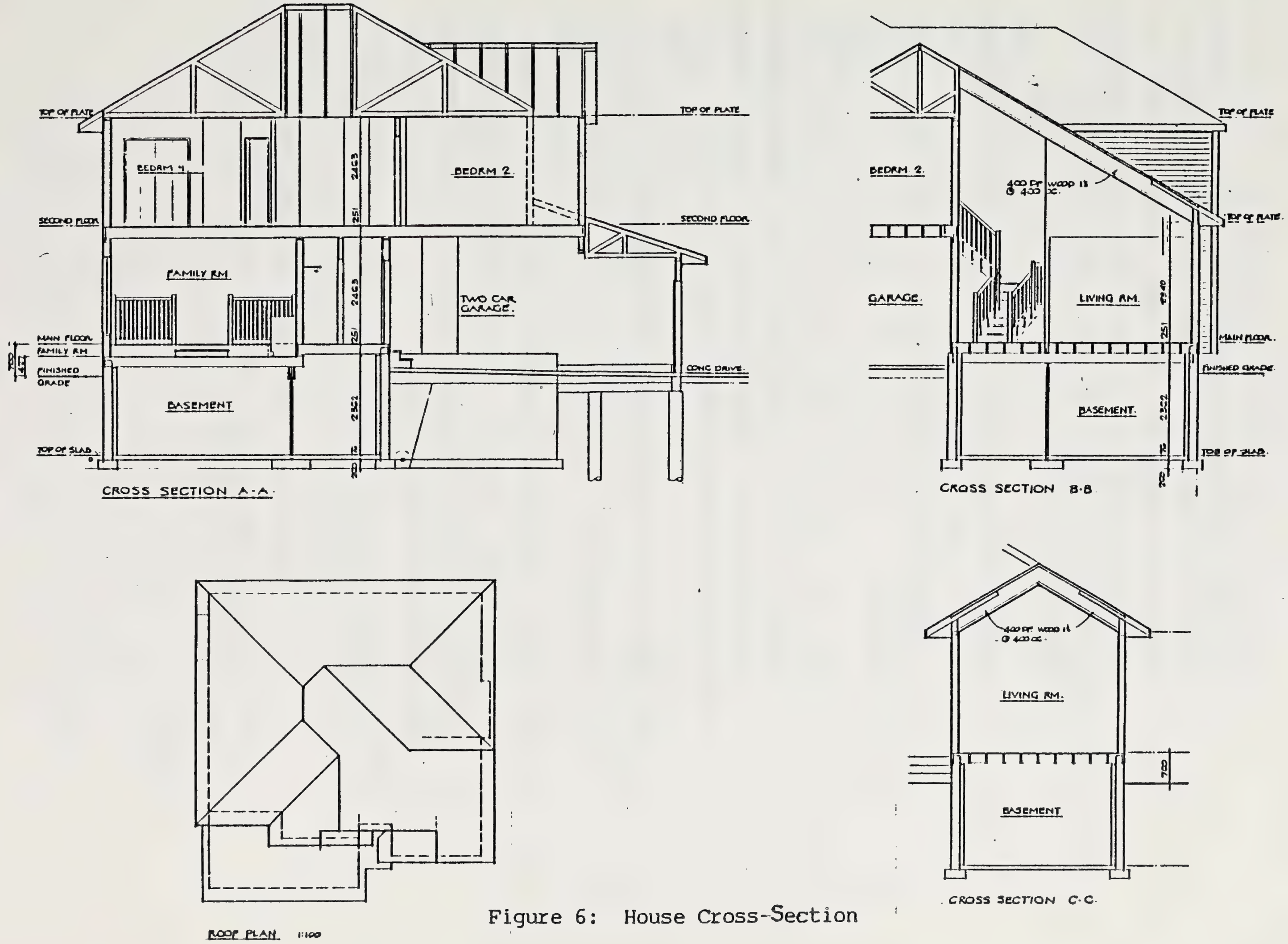

12200
CANTILEVER FL. JOISTS FOR BAY.
NON-FREEZE HOSE-BIB
AREA OF FLOOR SUNKEN 150 mm SHADED CONC WALL LOWERED 150 mm.
38×235 DF #2 @ 400 OC FLOOR JOISTS 1 ROW X.
2750
LOW BEAM.
2550
LOW BEAM.
1200
2700
3000
FURNACE
FLUE
HWT
4-38×235 DF #2 BM.
DO.
NOTE: 3 PIECE R.L.D.P.
ADJ. STEEL TELEPOST ON 900×900×200 CONC. FOOTING. (TYP.)
OUTLINE OF UP FLIGHT MAIN FLOOR.
ADJ. STEEL TELEPOST ON 750×750×200 CONC. FOOTING.
3-38×235 DF #2 BM.
GRADE BEAM TIED TO FOUNDATION WALL W/ 2-#10M × 1200 LG MIN. TOP & BOTTOM.
5250
1250
2250
3450
200×600 CONC. GRADE BM. REINF. W/ 2-#10M TOP & BOTTOM. ON 300 ø CONC. PILES × 3000 DP. MIN. REINF. W/ 4-#10M TIED TO GRADE BM.
GLU-LAM ABOVE.
860
4980
860
DOOR BUCK RECESS IN GRADE BM.
1200×400
CANTILEVER FL. JOISTS FOR BAY.
NON-FREEZE HOSE BIBB.
A
B
C
600
970
2000
6600
13300
1050
1850
6700
1850
1850
100
1250
2600
2850
1450
2200
4525
3575
11900
4000
2100
1400
100
1000
2250
2250
1000
100
6700
1500
4000
12200

Figure 5: Basement Plan



CROSS SECTION A-A

CROSS SECTION B-B

ROOF PLAN 1:100

CROSS SECTION C-C

Figure 6: House Cross-Section

in place of standard 10 mm spruce plywood. This combination gives the optimum air permeability conditions required for dynamic air intake, and ensures a consistent flow of air into the cavity normal to the wall surface. The practical advantages of the Glasclad sheathing include the elimination of thermal bridging through studs and plates, and the provision of backing material for the vinyl siding.

- Non-naturally-aspirated gas-fired appliances were installed.

- A central exhaust-only mechanical ventilation system was installed.

- The ADA techniques that were employed eliminated the potential for short-circuiting of the dynamic wall through air leakage paths. (ADA techniques are routinely used by the builder of the demonstration house.)

The construction specifications are summarized in Table 1.

3.1.3 The Envelope

The dynamic wall area was reduced by the area of openings in the envelope (windows and doors) and by the area of walls shared with the attached garage, as exterior air could not be drawn into the house through these.

The dynamic wall area is 23% (138 m^2/609 m^2) of the total envelope area or approximately 0.17 m^2 for every cubic metre of interior air. In the Timusk house, the dynamic wall area was approximately 48% (138 m^2/285 m^2) of the total envelope area, or 0.44 m^2 for every cubic metre of interior air.

Table 1

SUMMARY OF CONSTRUCTION SPECIFICATIONS

Component	Size and Material
Area	
Main floor	111.3 m^2 (1198 sq. ft.)
Second floor	107.0 m^2 (1152 sq. ft.)
Total	218.3 m^2 (2350 sq. ft.)
Volume	815 m^3
Envelope Area	
Gross	609 m^2
Envel. area above grade	426 m^2 (incl. windows and doors)
Wall area above grade	266 m^2 (not incl. windows and doors)
Dynamic wall area	138 m^2
Windows/doors	24 m^2
Envelope Construction	
Basement floor	Concrete, without insulation
Foundation walls	200 mm poured-in-place concrete
Framed walls	38 x 89 mm studs (fibreglass batts) plus 38 mm Glasclad
Ceilings	
- Flat trusses	
- Cathedral	356 mm deep wood-I joists

(cont'd)

Table 1 (cont'd)

Component	Size and Material
Insulation Levels	
Basement frost walls	RSI 2.1 (R12) to the floor
Framed walls	RSI 3.27 (R18.7) (R12 Batt + R6.7 Glasclad)
Ceiling	RSI 7 (R40) blown cellulose
Windows	Double-glazed wood casement
Mechanical	
Hot water tank	Induced draft (comb. air blocked)
Forced air furnace	Lennox "Pulse" high efficiency
Ventilation	
Exhaust	Fan (no heat recovery), rated for 94 L/s at 187 Pa, 62 W motor
Intake	Fan (for operation in balanced mode only)
Exterior Cladding	
Roof	Asphalt shingles
Walls	Vinyl siding over Tyvek (on Glasclad)
Soffits and fascia	Aluminum

3.1.3.1 Envelope Construction Details

The dynamic wall has the following cross-section (Figures 7 to 9):

- Vinyl siding
- 38 mm Glasclad sheathing
- 38 x 89 mm framed wall with RSI 2.1 fibreglass batt insulation
- 12.7 mm drywall

The use of 38 mm Glasclad rather than 10 mm spruce plywood as the exterior sheathing material necessitated attention to a number of additional details, particularly in framing. Some examples of these details follow:

(1) The garage grade beam was jogged out by 38 mm where the garage wall meets the house wall in the same plane in order to accommodate the transition from 10 mm plywood to 38 mm Glasclad.

(2) Longer trusses were required to accommodate the thickness of the Glasclad sheathing (a total of 75 mm for full trusses). On the other hand, where the mono-trusses above the garage interface with the house walls, the Glasclad was eliminated to allow the trusses to be properly secured. Careful attention was given to air and weather barrier details around the interface between the garage and the house (Figure 10). On the gable ends, 38 x 184 mm top plate backers were required for support (above the 38 mm thickness of Glasclad (Figure 11).

(3) Care was taken to install adequate backings for the attachment of all exterior finishes (e.g., at all corners, beneath the belly bands, around window and door openings, and at all roof - exterior wall intersections) (Figures 12 and 13).

(4) The window jambs were cut down to accommodate the reduction in wall thickness from 165 mm to approximately 152 mm. The

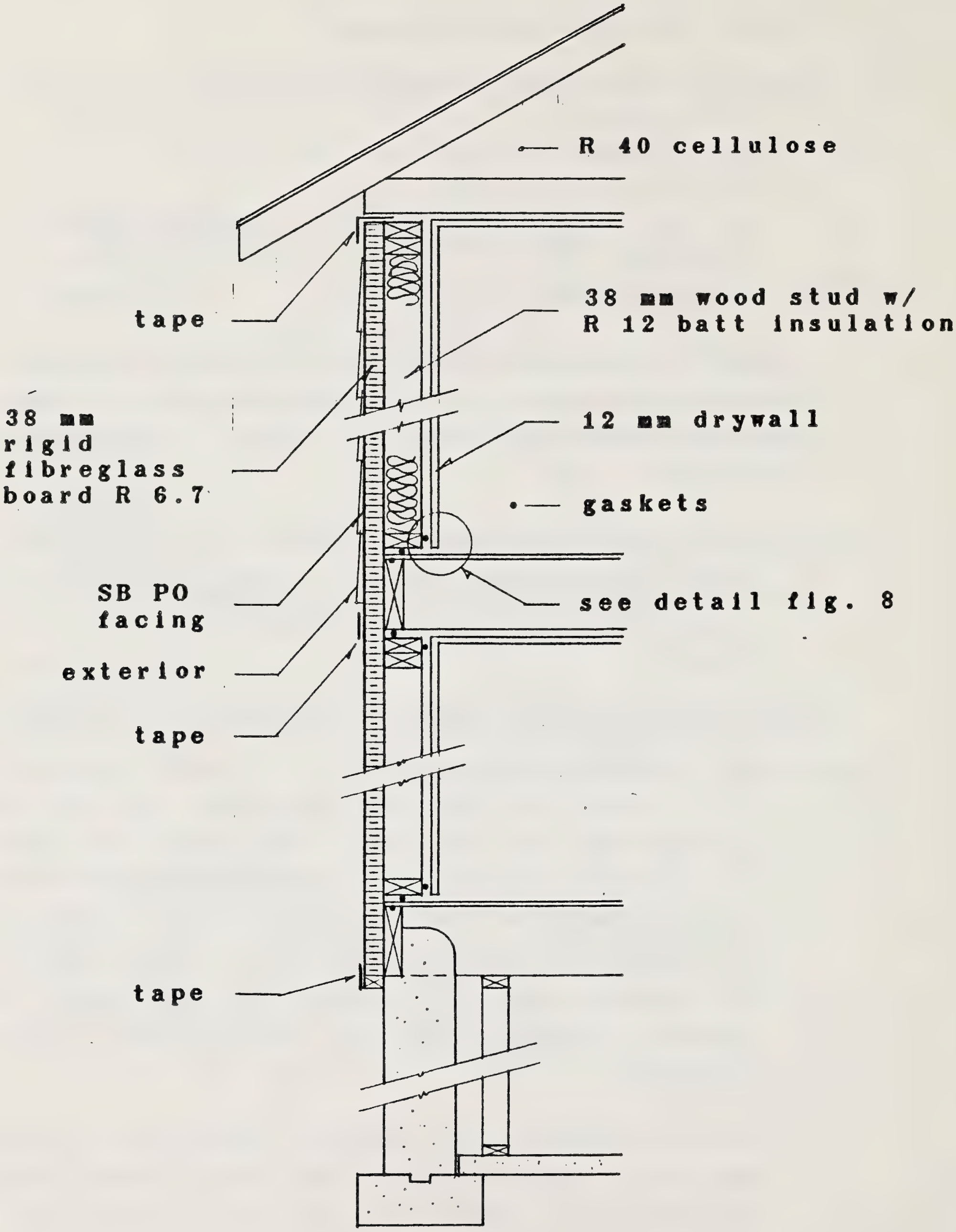


Figure 7: Typical Wall Section

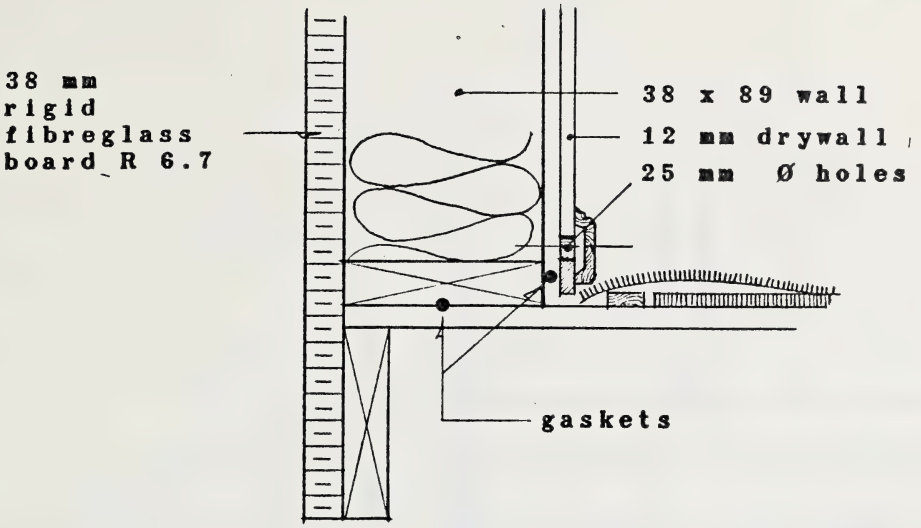


Figure 8: Cross Section of Baseboard Detail

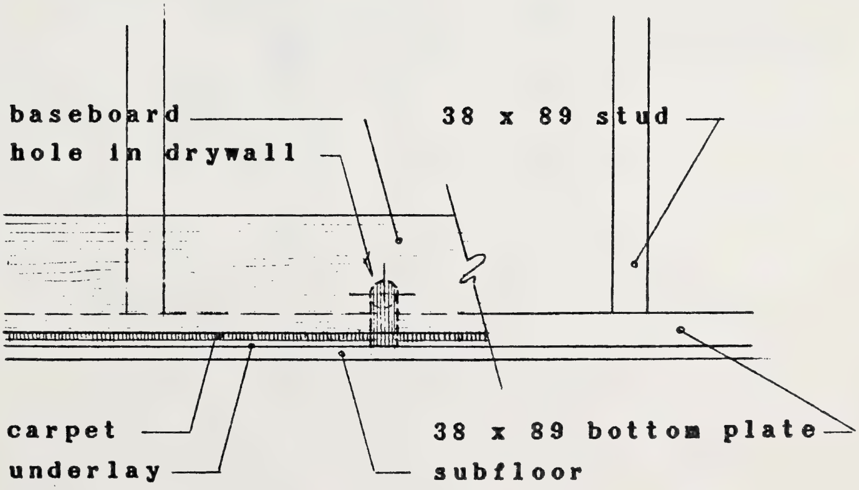


Figure 9: Front View of Baseboard Detail

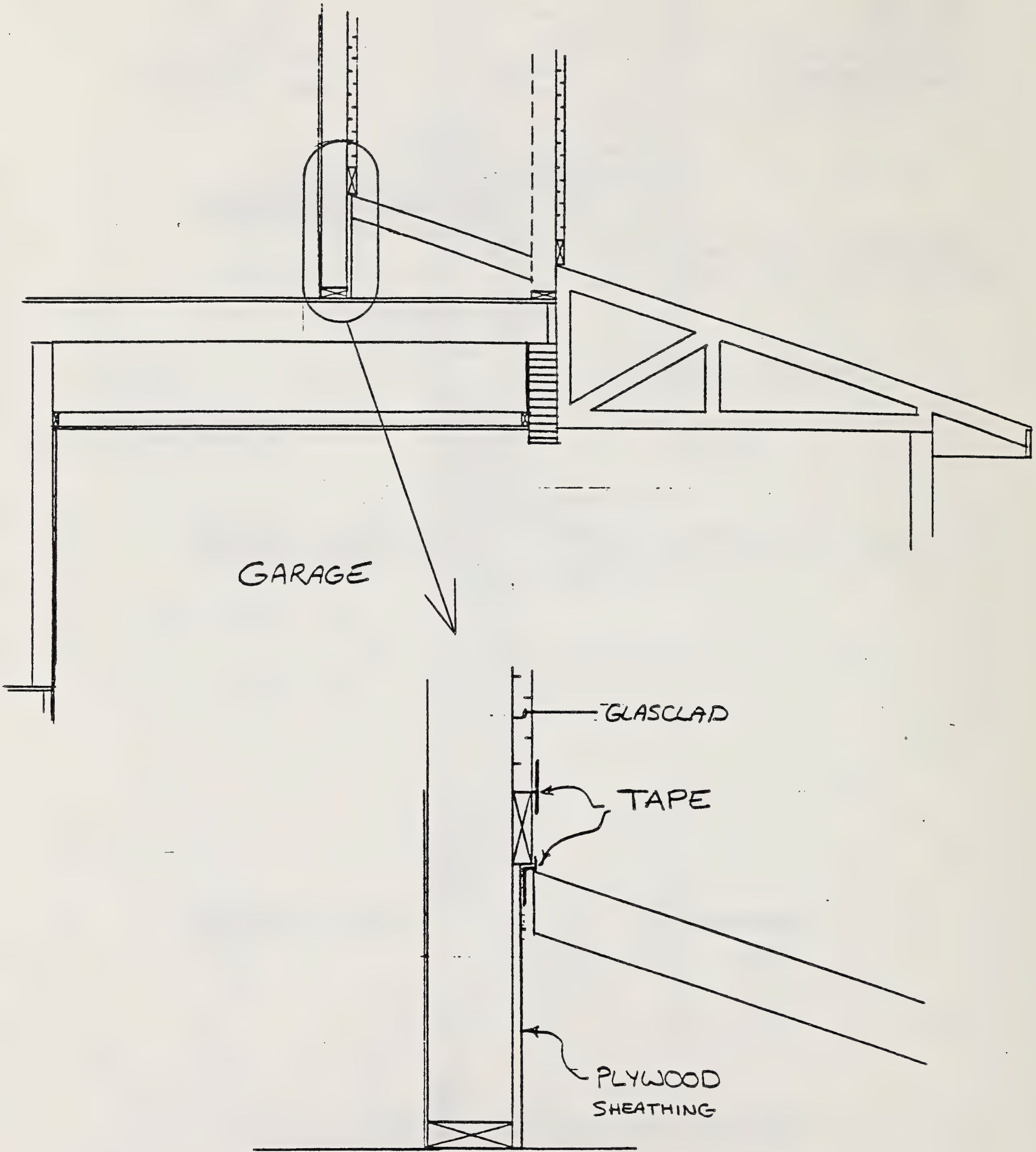


Figure 10: House-Garage Interface

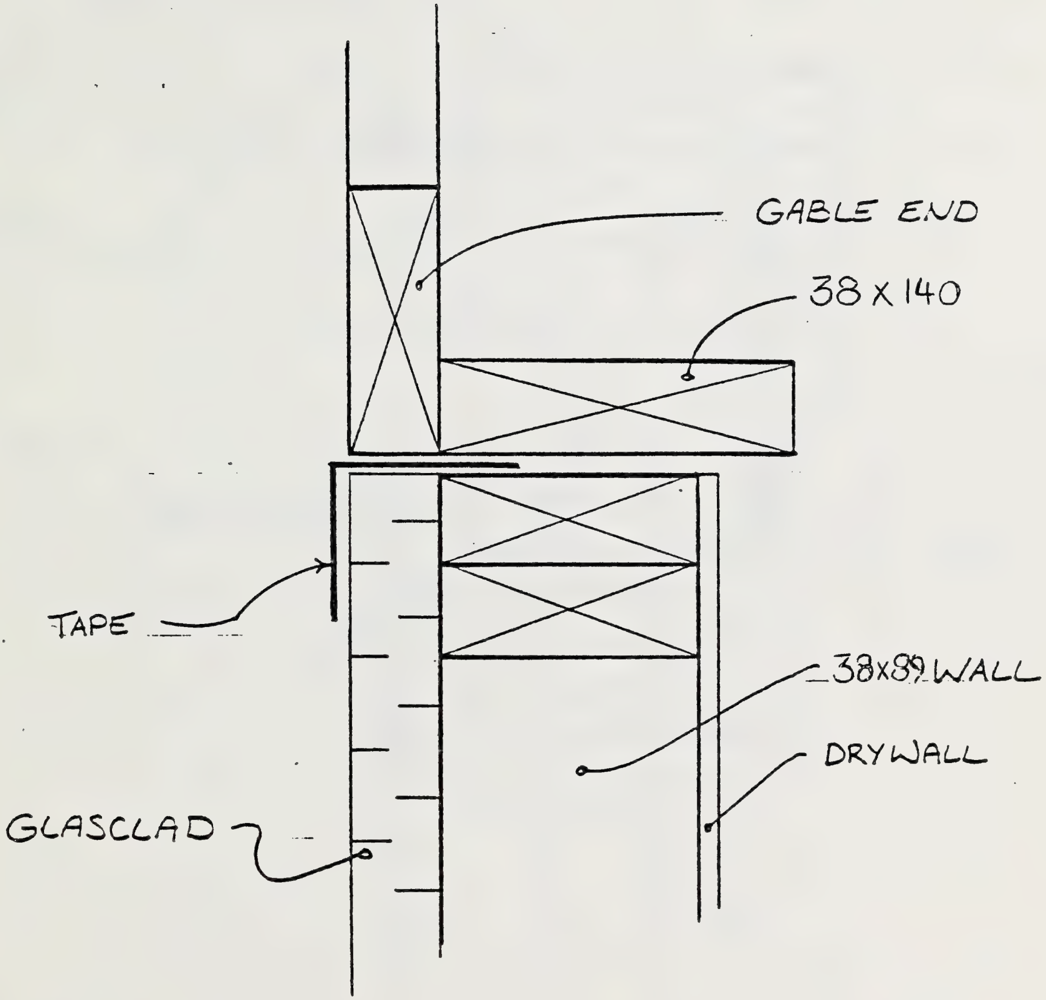


Figure 11: Gable End Detail

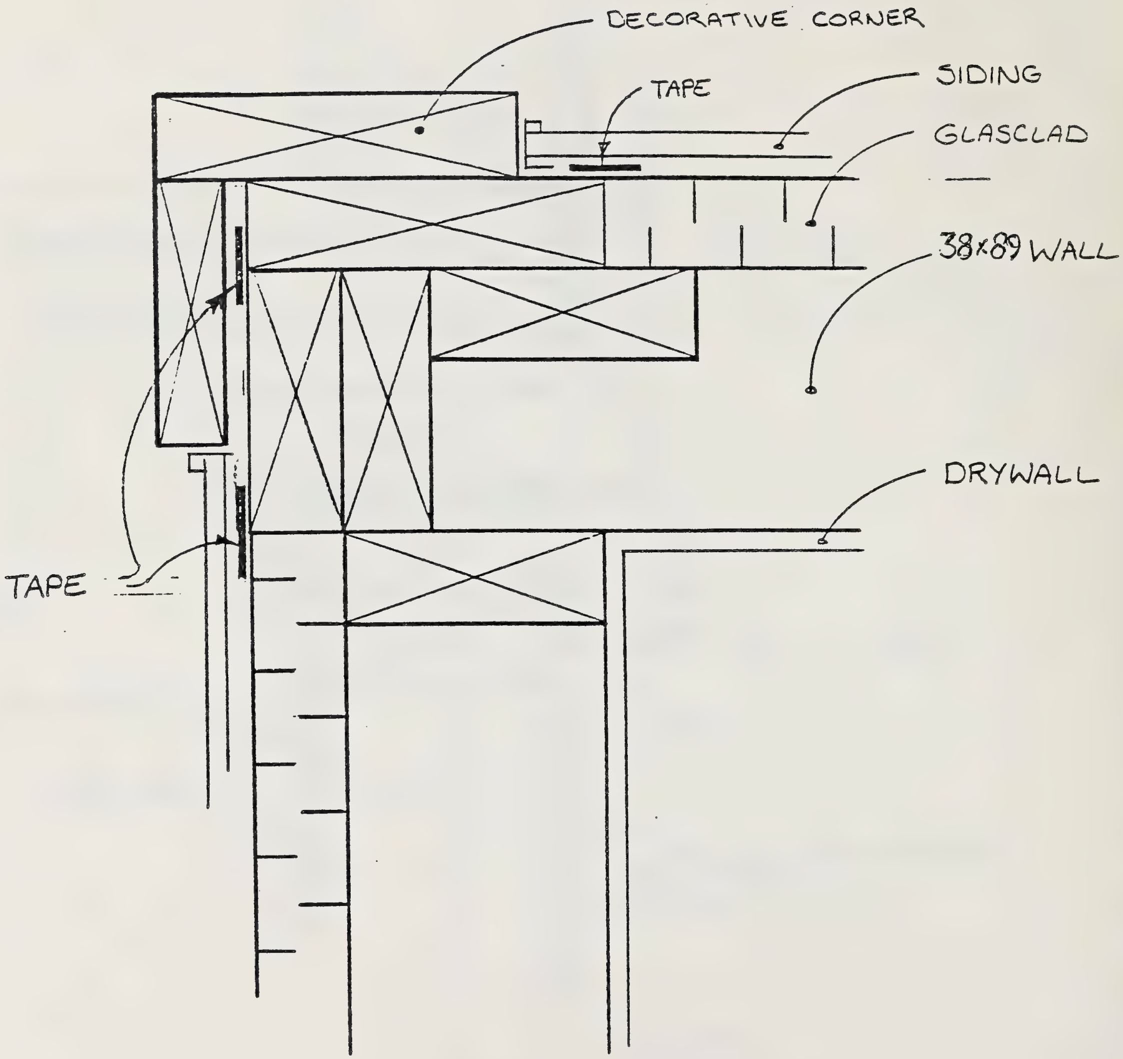


Figure 12: Exterior Corner Detail

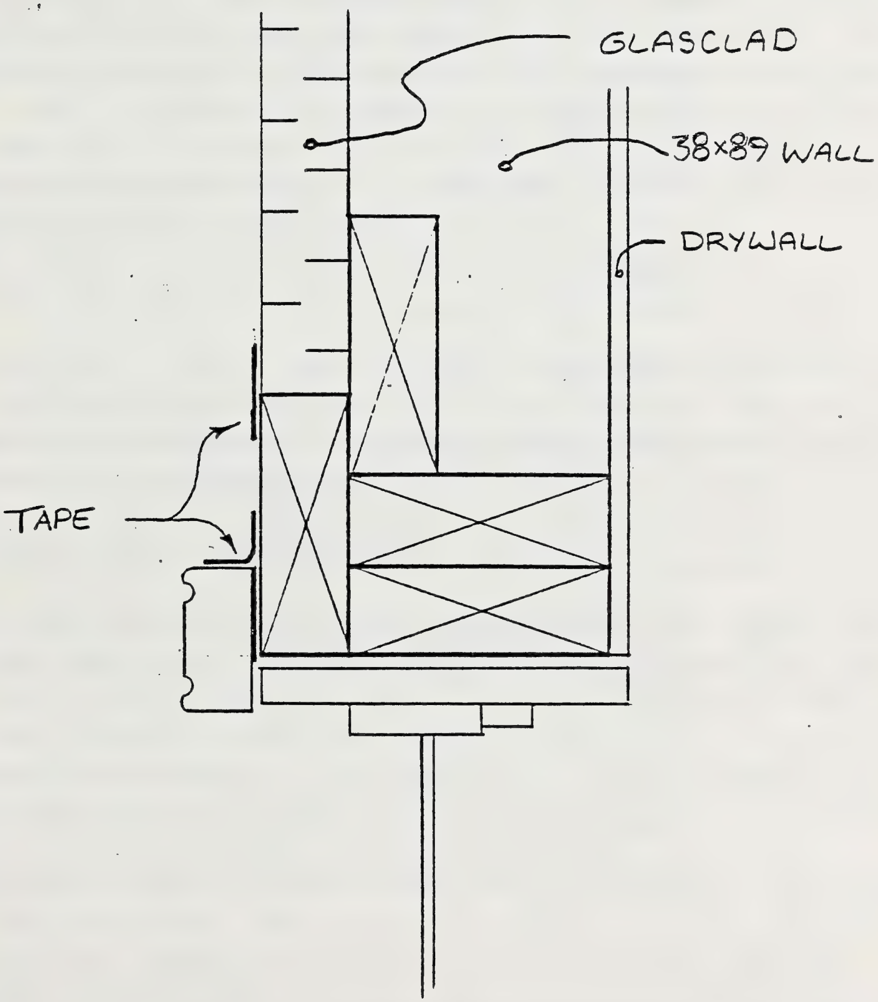


Figure 13: Window Opening Detail

garage-house walls, however, remained as standard 38 x 140 mm walls since they would not be used in the dynamic process.

In the future, proper window jamb depths could be ordered without additional cost. This would require some additional planning because of the various wall thicknesses created by the use of an insulating sheathing. If a 38 x 140 mm stud wall (vs. 38 x 8 mm) were used with a 38 mm insulating sheathing, then there would be an incremental cost for the windows (jamb widths greater than 165 mm).

(5) The door jambs could not easily be reduced in thickness because of the metal sills so the front door wall, the garage-house wall, and the kitchen nook bays were built as standard 38 x 140 mm walls.

3.1.3.2 Envelope Airtightness

Although it was not immediately apparent that an interior air barrier was necessary (since the airtightness of the envelope was ultimately reliant on the Tyvek weather barrier), maintaining ADA procedures for envelope airtightness ensured the following:

(1) The airtightness of some wall areas that could not be included in the dynamic air process (such as the house-garage walls)

(2) Elimination of any short-circuiting of the envelope through miscellaneous openings, thus allowing the exhaust fan to create enough negative pressure to draw air through the wall cavities

The outside air barrier, as previously noted, is the Tyvek facing of the Glasclad sheathing panels. Joints between panels were sealed with special Tyvek tape. This tape was also applied to all Glasclad-wood surface interfaces: the 38 x 38 mm sill, the top plate of the exterior walls, the window frames, and the backing lumber used for mechanical penetrations of the Tyvek surface.

3.1.4 Fibreboard Test Panel

The Glasclad was the most expensive incremental cost item in the construction of the demonstration house, and a recent study by Canada Mortgage and Housing Corporation (CMHC) has shown that a fibreboard-Tyvek combination is very close to the air permeability of Glasclad. Based on these two facts, the fibreboard-Tyvek combination was tested by removing a 4-foot-wide section of Glasclad sheathing in the south wall of bedroom #4 and installing a panel of fibreboard and Tyvek in its place. The 38 x 89 mm framed wall was shimmed to accommodate the reduced thickness of exterior sheathing before the fibreboard and Tyvek were cut to size and installed (Photograph 4).

3.1.5 House Systems

The overall concept (Figure 14) used an exhaust-only mechanical ventilation system with non-naturally-aspirated gas appliances that were not affected by the depressurization levels required for operation in the dynamic mode.

3.1.5.1 Heating and Ventilation

A Lennox Pulse furnace with a dual speed fan was chosen to eliminate the need to monitor the amount of air exhausted by the space heating combustion process. The rated efficiency of this type of furnace is much more reliable than that of an induced draft furnace, making it possible to more accurately calculate the energy consumed for space heating.

Low-speed operation of the furnace fan is not required for air circulation during the depressurized "dynamic" mode of operation since the furnace is not required for distribution of fresh air. However, during the summer, to prevent dynamic air from contributing to overheating, it may be necessary to switch the ventilation system from the dynamic mode to a balanced pressure "static" mode of operation. To accommodate this requirement, an intake fan (identical to the exhaust fan) was installed to provide

Photograph 4: Fibreboard Test Panel

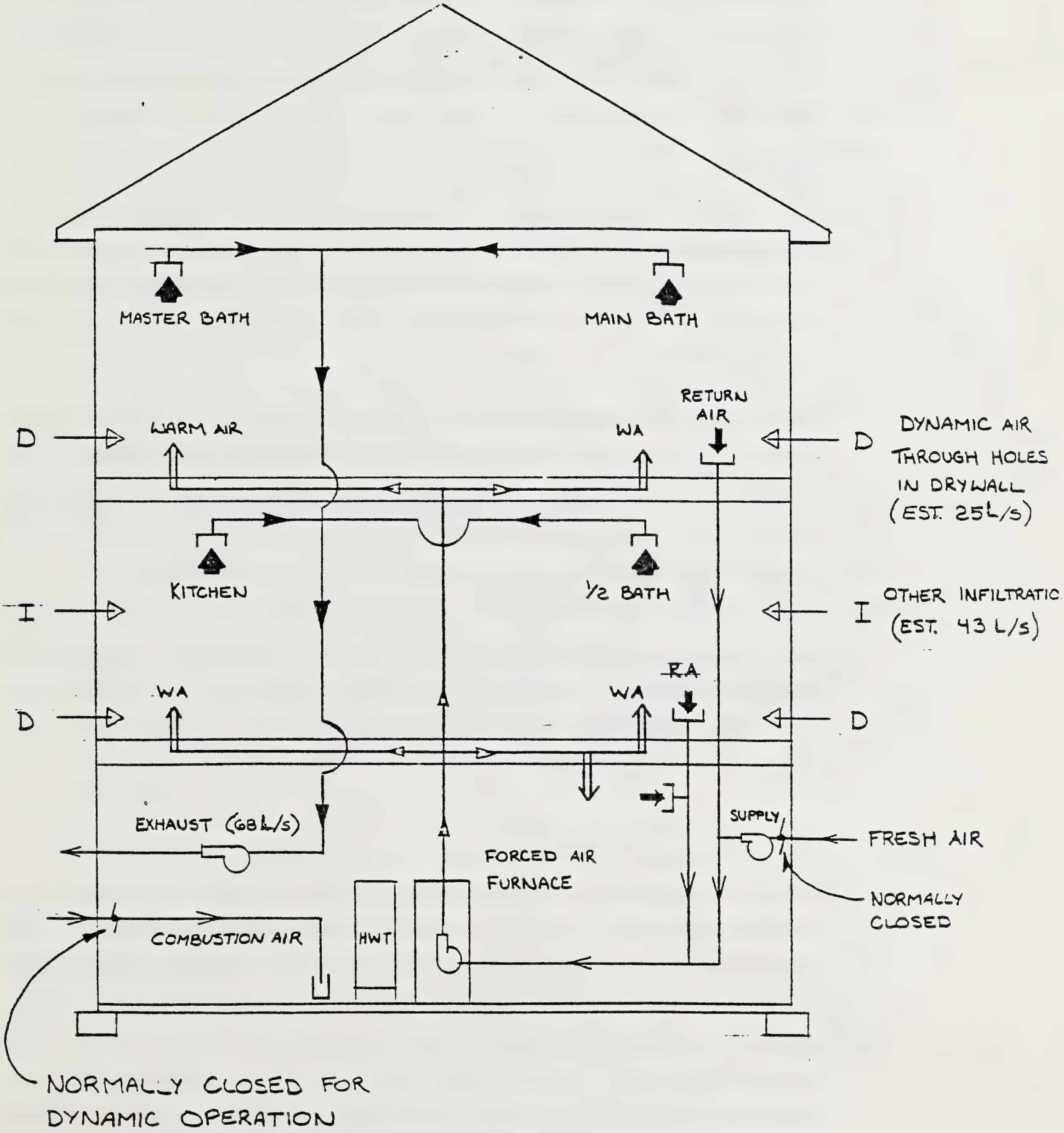


Figure 14: Mechanical System Schematic

fresh air to the furnace return air plenum via a 175 mm diameter duct. In the static mode, fresh air brought in through this duct to the return air plenum is distributed by the normal operation of the forced air furnace. This configuration also allowed the system to be operated in a balanced pressure "static" mode during testing in order to monitor the performance of the envelope in this mode.

Since the hot water tank installed is an induced draft appliance, the current code required the installation of a 100 mm combustion air duct from the exterior to a "bucket" near the hot water tank. The openings for this duct and the fresh air duct were taped over to eliminate these penetrations of the envelope while the house was operated in the dynamic mode.

The exhaust-only mechanical ventilation system consists of a Torin AMU 400 squirrel cage fan located in the furnace room area in the basement of the house. This fan draws its air from the kitchen and the bathrooms on both the main and second floors of the house.

3.1.5.2 Hot Water Heating

The induced draft hot water tank that was installed increased the amount of exhaust air during its operation, but as its operating time was limited, the performance of the house was not significantly affected.

3.1.5.3 Electrical System

Some relatively minor adjustments were made to conventional wiring methods in order to minimize the impact of the wiring on the airtightness of the envelope. As many light fixtures as possible were installed at inside wall locations instead of the ceiling (attic). The rear exterior wall plug was installed in the bay window area where the exterior sheathing is plywood rather than Glasclad, and the exterior light was installed in the soffit instead of the wall. At the front of the house, the front door exterior light was installed on the garage wall.

Holes drilled for electrical penetrations of the air barrier were made as small as possible and were properly caulked.

3.1.6 Other Details

Holes 25 mm in diameter were drilled through the drywall at baseboard level into each exterior dynamic wall cavity to allow dynamic air to enter the rooms. The dynamic air flows were measured by a calibrated 25 mm PVC pipe and a hot wire anemometer.

The drywall below the 25 mm holes was removed to allow the air to enter the house behind the baseboard and at the interface of the carpets and the bottom of the baseboard.

3.1.7 Costs

Costs of the dynamic wall house were recorded for subsequent comparison and evaluation (Section 4.7).

3.2 TESTING FOR CONFIRMATION OF OPERATION

The tests carried out to confirm whether the demonstration house operated as intended included airtightness testing by the blower door depressurization method, measurement of wall surface temperatures using an infrared camera and infrared pyranometer, measurement of air flow through the dynamic cavities, and measurement of temperature and pressure profiles within the cavities.

Testing was carried out in the spring and summer of 1989. In addition to assessing as-built conditions and system performance, the testing permitted adjustment of the components of the long-term monitoring system. Direct access to dynamic air inlet holes was required to confirm air flow, so the baseboards were not installed until October of 1989 when verification testing was completed.

3.3 LONG-TERM OPERATIONAL MONITORING

A computerized monitoring system was used to collect data continuously over the 1989-90 heating season in order to record, analyze, and describe the operation of the dynamic wall system in the demonstration house.

Instrumentation was also installed for the purpose of measuring various indoor air quality parameters, and a questionnaire was developed to determine the occupants' comfort level.

3.3.1 Monitoring and Sensing Equipment

The monitoring and sensing equipment used in the monitoring program is described in the following lists:

Monitoring Equipment

(1) An XT-compatible computer complete with monitor and keyboard and containing one mini-floppy drive and one 20 Mb hard drive.

(2) A Sciemetric 8082 Electronic Measurement System (EMS) comprising 64 differential analog input channels and 16 digital input channels to collect the data stored by the computer.

(3) A Sciemetric 802 card to interface the EMS and the computer.

(4) A multiplexer unit (MUX) for reading pressure differentials.

(5) A Watchdog Timer to automatically restart the computer monitoring system in the event that the monitoring program should "hang" and monitoring be suspended.

Sensing Equipment

(1) Thermocouples to measure temperatures. The thermocouple wire was Type T, teflon-coated, offering excellent moisture and abrasion resistance and useful from -65°C to +240°C.

(2) A General Eastern RH-2 ductmount sensor mounted in the furnace return air duct to measure relative humidity.

(3) A Sentra - 264 differential pressure transmitter having an air pressure range of ± 0.1 in H_2O. Its accuracy is ± 1% of full scale in normal ambient temperature conditions.

The pressure transmitter was used in conjunction with the multiplexing valve which rotated through the different pressure positions as the transmitter read the selected pressure. The pressure lines consisted of 1/8" rigid air brake tubing.

(4) Flow measuring stations utilizing pitot tube arrays and manufactured by Conservation Energy Systems to develop the airflow pressure outputs. These were installed in the intake and exhaust air ducts.

(5) A carbon monoxide (CO) sensor manufactured by COSENSOR International to monitor backdrafting of the fireplace. The device produces digital output signals when CO levels exceed 20 and 40 ppm.

(6) An R.M. Young Wind Monitor mounted 2 metres above the highest point of the house to measure wind speed and direction.

(7) A Kipp and Zonen C-35 pyranometer mounted at the highest peak of the house to measure horizontal solar radiation.

3.3.2 Computer-Measured Parameters

The parameters measured by the monitoring system and the sensors used for each are listed in Table 2. A total of 95 input channels were specified, of which 90 were actual data collection points in the dynamic wall house. However, due to the limited number of channels in the data acquisition unit and the multiplexing valve, only 11 pressure points and 62 electronic sensors could be monitored simultaneously.

Table 2

COMPUTER-MEASURED PARAMETERS AND SENSORS

Computer-Measured Parameters	Sensor	Quantity
Typical Ambient Conditions		
Outdoor air	Thermocouple	1
Attic temperature	Thermocouple	1
Wind speed and direction	Vane anemometer	2
Horizontal solar radiation	Pyranometer	1
Indoor Temperatures		
Mid-wall height, interior walls of master bedroom, NW bedroom, living room, family room, basement	Thermocouple	5
Floor level, interior wall of NW bedroom, living room	Thermocouple	2
Dynamic Wall Air Temperatures		
8 locations guarded by radiation and draft shields	Thermocouple	8
Wall Cavity Temperature Profiles		
Top, middle, and bottom of a dynamic and fibreboard cavity in south wall - Behind siding - At Glasclad/batt fibreboard/ batt interfaces - Mid-cavity - At batt/drywall interface	Thermocouple	24
Top and bottom of a dynamic wall cavity on N, E and W walls - At Glasclad/batt interface - At batt/drywall interface	Thermocouple	12

(cont'd)

Table 2 (cont'd)

Computer-Measured Parameters	Sensor	Quantity
Wall Cavity Temperature Profiles (cont'd)		
Middle of a dynamic wall cavity on N, E and W - Behind siding - At Glasclad/batt interface	Thermocouple	6
Indoor Relative Humidity		
Main floor	Capacitance	1
Envelope Pressure Differences		
Pressure difference - Mid-height of each wall, on each floor and across the ceiling - Rim joist area between main and second floors along south and west walls - Rim joist area in basement along each wall - Mid-cavity, second floor, west wall	Multiplexing unit (MUX)	16
Other Parameters		
Fireplace backdrafting	CO sensor	2
Exhaust fan flow rate	MUX	1
Intake fan flow rate	MUX	1
Fireplace status	Thermocouple	1
Gas meter (to measure space heating energy consumption)	Reed switch	1
Thermocouple junction temperatures	Thermocouple	2
Pressure transmitter output	Transducer	1
Multiplexing unit (MUX)	Digital output	1
Watchdog timer	Pulse output	1

3.3.3 Measurement of Indoor Air Quality

3.3.3.1 Passive Air Change Tests

The ability to predict the actual air exchange rate of the house at various ventilation rates is deemed useful in any discussion of air quality. Consequently, perfluorocarbon tests were done using the Air Infiltration Measuring Service (AIMS) testing procedure developed by Brookhaven Laboratories to measure actual air exchange rates. One test was done while the house was under negative pressure and operating in the dynamic mode, and another when the house was in the static mode.

3.3.3.2 Radon

Radon presently receives considerable public attention, and is one of the first recognized air pollutants to be addressed by a specific mitigation procedure in the National Building Code. Also, the belief persists that negative pressure within the building envelope could encourage the entry of radon to the living space. Thus, although Alberta is not considered a high-risk area for radon, the house was checked. Three radon survey meters were installed in the house from March 15 to March 20, 1989; one was located in the basement and two in the living room (one next to a dynamic wall air inlet).

3.3.3.3 Formaldehyde

Formaldehyde was one of the first air pollutants studied by the building science community as a potential health hazard. Major contributors to formaldehyde in houses are tobacco smoke, some adhesives, and synthetic materials such as particle board and polyester fabrics. The off-gassing of formaldehyde from synthetic materials and adhesives in building materials (e.g. particle board) decreases over time; however, high humidity and temperature tend to speed the release of formaldehyde gas from these materials.

Since the demonstration house was new construction, the carpets and other building materials constituted relatively high off-gassing sources. The occupants were non-smokers.

Formaldehyde concentrations were measured by dosimeters during three periods with the ventilation system operating in different modes:

(1) Dynamic operation with mechanical ventilation at 0.3 ACH

(2) Static operation with the fresh air and combustion air ducts open and the furnace running on continuous low speed

(3) Static operation with the combustion and fresh air ducts taped closed

3.3.3.4 Glass Fibre

The radon sampling pump located at one of the dynamic air inlets was also used to monitor the presence of glass fibre particulates.

3.3.4 Homeowner Comfort

A questionnaire was developed to determine the occupants' perception of comfort and air quality in the house while it was operated under the three ventilation conditions used to check formaldehyde levels.

3.4 MONITORING SCHEDULE AND DATA

Performance monitoring commenced in November of 1989 following baseboard installation. At this stage, the demonstration house was fully complete and ready for occupancy. In November, problems were experienced with the data acquisition unit, and as a result, the data collected for November was deemed unreliable. Usable data was collected from December through March of 1990. The house was first occupied in mid-January, 1990.

Monthly data summaries for December through March are included in Appendices C, D, and E. The entire data set has been divided into eight smaller data sets to facilitate analysis and allow the reader to more easily reference the data in the appendices.

The eight data sets cover the following time periods:

Data Sets 1-4	Data Sets 5-6	Data Sets 7-8
(1) DE 07-15	(5) JA 03-07	(7) DE 18-31
(2) JA 19-28	(6) JA 09-12	(8) FE 03-14
(3) FE 18-28		
(4) MR 01-29		

Data Sets 1-4

These data sets represent periods of dynamic operation during which the exhaust fan was operating at a maximum capacity of approximately 72 litres per second (L/s), or 0.32 air changes per hour (ACH). The supply air and combustion air ducts were blocked during these periods. During the period represented by Data Set 1, the house was not yet occupied.

Data Sets 5-6

These data sets from January 1990 represent periods of dynamic operation at less than maximum exhaust rates. During the period represented by Data Set 5, the exhaust fan was operating at 53 L/s, or 0.23 ACH. During the period represented by Data Set 6, the exhaust fan was operating at 64 L/s, or 0.28 ACH. The fresh air and combustion air ducts were unblocked during this period.

Data Sets 7-8

These data sets from December 1989 and February 1990 represent periods of static operation during which the exhaust fan was not operating, and the fresh and combustion air ducts were unblocked.

NOTE: The data collected at the dynamic air inlet hole on the west wall of the second floor, although verified for accuracy, was not used in the analysis. An examination of the temperature data indicated abnormally low dynamic air temperatures at this location, especially in colder weather. It was concluded that this was due to a tear in the Tyvek air barrier. A similar tear had been discovered and repaired on the main floor (east wall) during thermography testing in March 1989.

4.0 FINDINGS

4.1 TEMPERATURE PROFILE OF THE ENVELOPE

Temperature thermocouples were installed as described in Section 3.3.1. Thermographic scanning of the interior walls of the house was done by International Radiography and Inspection Services (1976) Ltd. During the test period, 6:00 a.m. to 8:30 a.m. on March 20, 1989, the outdoor temperature was approximately -10° C.

Thermographic scans did not reveal any significant anomalies, confirming that the Tyvek air barrier was effectively distributing the infiltration of cold ventilation air over the building envelope of the house. The wall plates and studs were slightly cooler than the rest of the wall surface. The infrared pyranometer indicated a temperature difference of approximately one Celsius degree between the wall cavity area and the studs. The coolest temperatures were in the corners, where additional framing members displace insulation material.

4.1.1 Kitchen-Family Room Area

Cool areas included the box-out for the stove hood and the bay window area, where there are more wall studs.

4.1.2 Living Room

The roof joists and studs in the cathedral ceiling were noticeable as thermal bridging areas. A small section of the east wall of the living room was cooler than the surrounding areas. Subsequent measurements of flow rates showed higher-than-expected air flows through some dynamic cavities in the living room. When the siding was removed, cuts in the Tyvek were revealed almost exactly opposite the holes with the high air flows. Thus, the slow flow of air down the length of the wall cavity can be short-circuited by breaks in the exterior air barrier close to the dynamic air entry point. Investigation showed that there were other cavities with similar cuts in the Tyvek, but when they were a reasonable distance from the holes, the cuts had very little effect.

4.1.3 Windows

Windows were about two Celsius degrees colder at the edges of the panes than in the centres. The temperature of the glass in the moveable sash was approximately one Celsius degree lower than that of the glass in the fixed sash, probably due to air leakage.

4.1.4 Basement

The temperatures of the inside surfaces of the basement were as follows:

Slab (centre)	12°C
Slab (edge)	11°C
Frost walls	14-15°C

4.1.5 Northwest Bedroom Floor (over garage)

The temperature of the floor decreased from 18°C at the house-garage interface to 15°C at the outside (north) wall of the bedroom.

4.1.6 Static vs. Dynamic Operation

The infrared camera recorded a drop in wall surface temperatures as the house was switched from static to dynamic operation (with the ventilation rate set at 0.3 ACH). Infrared pyranometer measurements indicated a drop of one Celsius degree, with the temperature stabilizing approximately 10 minutes after the switch from static mode.

The pyranometer was also used to measure temperatures of specific areas of the envelope. Wall temperatures at stud locations were approximately one Celsius degree lower than those over an insulated cavity.

4.2 DYNAMIC AIRFLOW RATE

4.2.1 Airtightness of the Envelope

It is assumed that the airtightness of the envelope must be about 1.5 ACH at a 50 Pa pressure differential for sufficient depressurization to occur at the continuous ventilation rate (approx. 0.3 ACH) to allow equal distribution of dynamic air flow throughout the envelope.

Test results indicated that the airtightness of the envelope was within this range. Blower door test results indicated an air change rate of 0.93 ACH with the interior drywall intact and 1.31 ACH with the 25 mm dynamic air inlet holes drilled. An airtightness test done approximately 10 months after completion of the house provided a result of 1.57 ACH. The reason for the difference between the two test results was suspected to be a combination of ambient test conditions and airtightness deterioration. The second test took place in February 1990, and the holding power of the tape used to seal vent hoods was somewhat compromised by the extremely cold temperatures.

In comparison, in the Timusk house the rate of air change at 50 Pa was 1.33 ACH with the drywall intact and 1.51 ACH with the 25 mm holes in the drywall.

4.2.2 Dynamic Air Flows

Airflow measurements indicated that approximately 30% (19.77 L/s) of the total ventilation air was entering through the dynamic air inlets, or approximately half of the percentage of total ventilation air measured in the Timusk house. The variance between these quantities may be explained by the fact that the ratio of the dynamic wall area to the total envelope area in the demonstration house (0.23) is much smaller than that of the Timusk house (0.48).

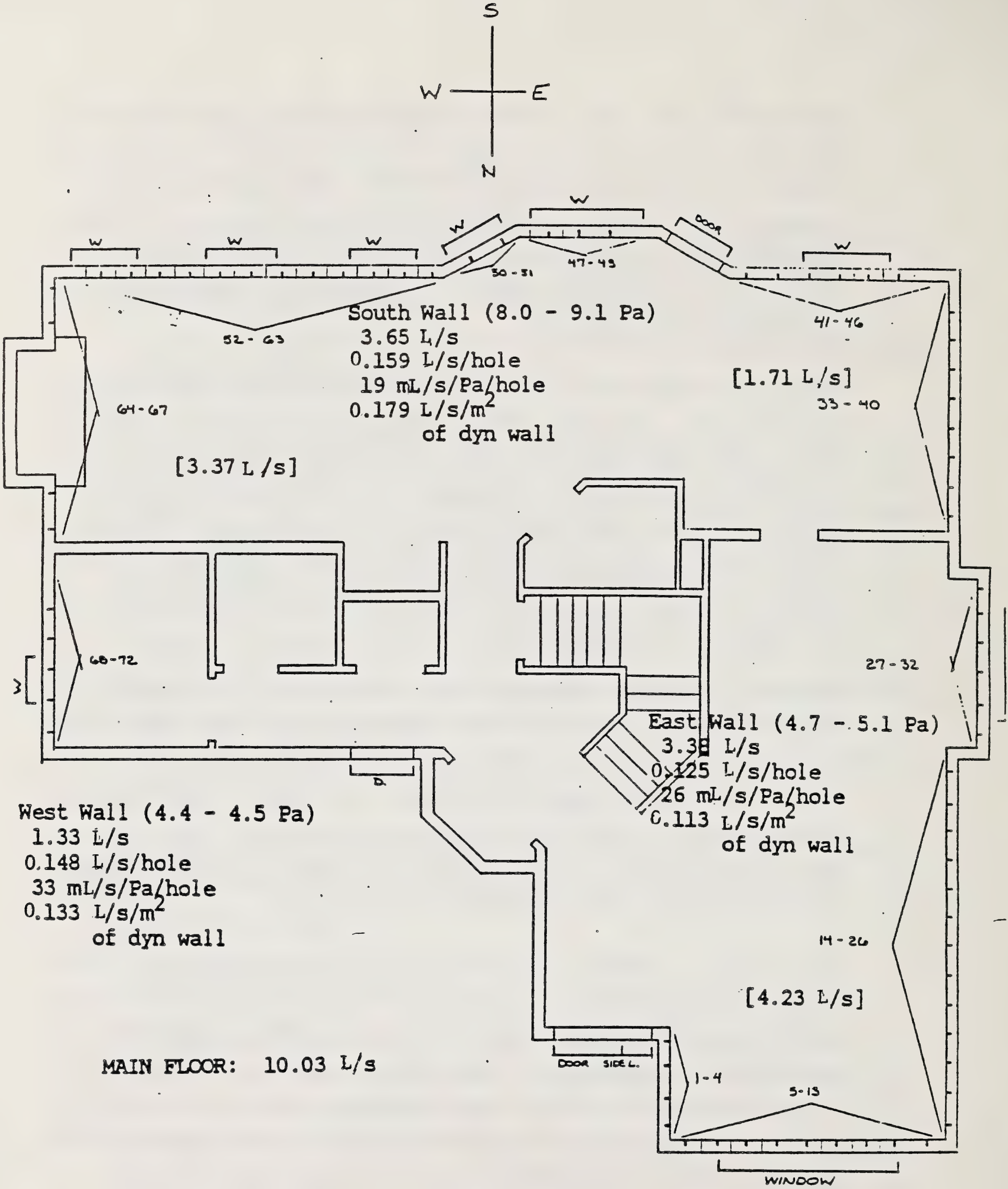
Appendix A contains the blower door test data, and this data is analyzed in Appendix B. The analysis indicates that at a total ventilation flow rate of 65 L/s, the pressure drop across the envelope would be approximately 5 Pa and the flow through the dynamic air holes approximately 23 L/s. This prediction is very rough for many reasons, including the fact that the data at these pressures are an interpolation of the more accurate readings in the 20 to 60 Pa range. However, it appears to confirm that the measurements are realistic.

Some other observations were made during the course of the airflow measurements. Initially, some of the inlets had very little air flow. When the insulation was pushed away from them, the flow increased significantly; the volume of air flow appeared to almost double. On the other hand, there was no additional flow from a cavity when a second hole was drilled through the drywall into a dynamic wall cavity. Significant increases in flow occurred on the windward side of the house.

Figures 15 and 16 illustrate the locations of the dynamic air inlets and the volumes of air entering the house from each direction and into each room. All data except kitchen data are from measurements made on October 3, 1989. The airflow measurements for the kitchen were made on March 20, 1989, prior to the installation of the kitchen cabinets. The pressure measurements were made on October 3, 1989.

The amount of dynamic air flowing into the house appears to vary in direct proportion to the area of the applicable dynamic wall and the pressure applied across that wall. This relationship is true for all directions on both floors except for the north wall of the second floor where a number of roof intersections with the exterior wall increased the probability of direct leakage paths into the dynamic wall cavities.

Ventilation air was well distributed throughout the house. The forced air system in the demonstration house mixes ventilation air with return air, so the house is capable of providing approximately 17.5 L/s of continuous ventilation per occupant (based on four occupants) with the exhaust fan operating at



South Wall (8.0 - 9.1 Pa)
3.65 L/s
0.159 L/s/hole
19 mL/s/Pa/hole
0.179 L/s/m^2
of dyn wall

[1.71 L/s]

[3.37 L/s]

East Wall (4.7 - 5.1 Pa)
3.38 L/s
0.125 L/s/hole
26 mL/s/Pa/hole
0.113 L/s/m^2
of dyn wall

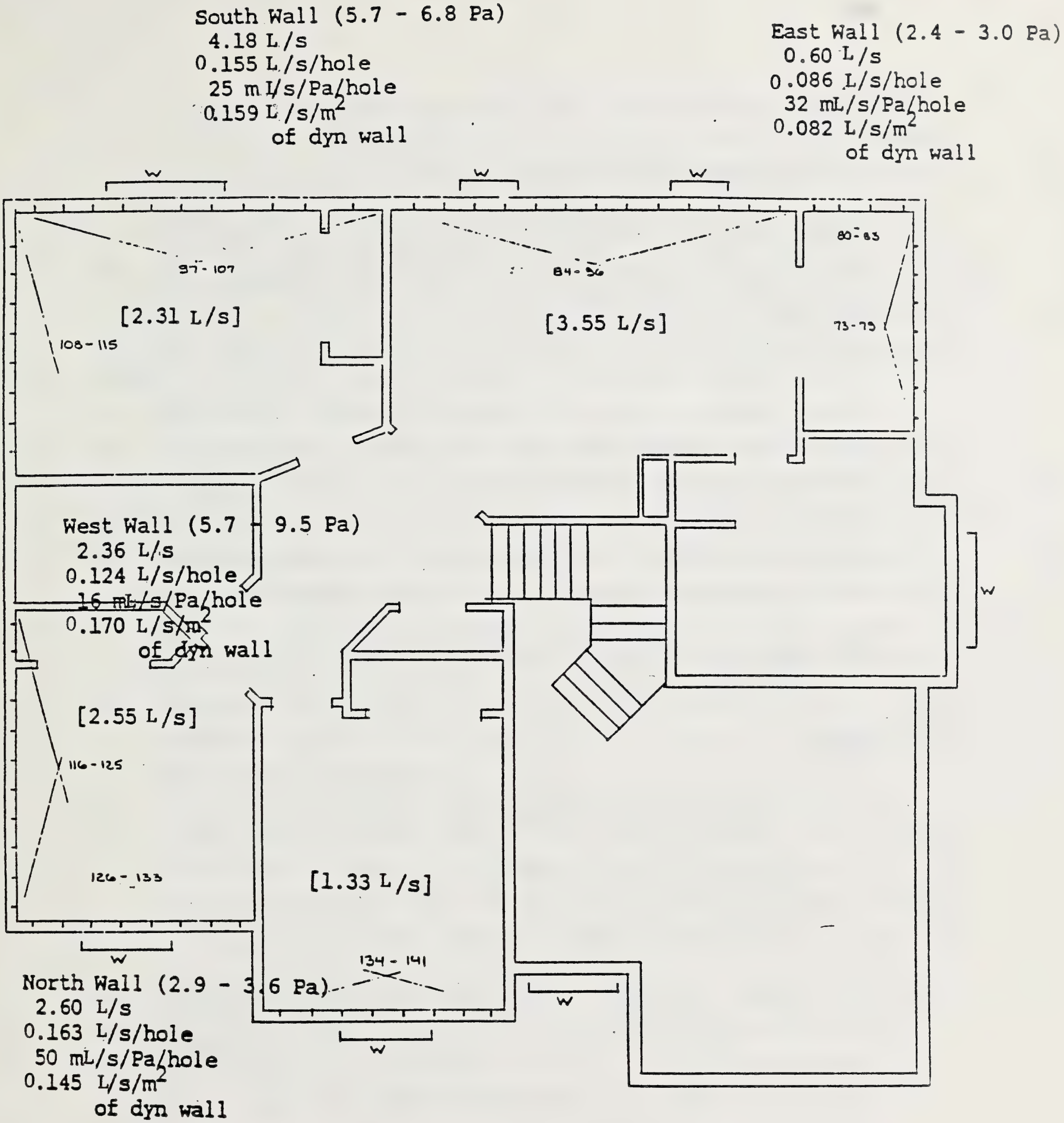
West Wall (4.4 - 4.5 Pa)
1.33 L/s
0.148 L/s/hole
33 mL/s/Pa/hole
0.133 L/s/m^2
of dyn wall

[4.23 L/s]

MAIN FLOOR: 10.03 L/s

North Wall (5.8 - 5.9 Pa)
1.67 L/s
0.128 L/s/hole
22 mL/s/Pa/hole
0.138 L/s/m^2
of dyn wall

Figure 15: Dynamic Air Flows: Main Floor



SECOND FLOOR: 9.74 L/s

Figure 16: Dynamic Air Flows: Second Floor

0.3 ACH.

4.2.3 Optimum Dynamic Airflow Velocity

Optimum velocity is defined by Timusk (1987) as "the velocity of ventilation air through the insulation at which all the heat conducted through the still air in static insulation is transferred to the ventilation air." Based on the heat and mass transfer model presented by Timusk, at the optimum, or maximum "free" ventilation rate, the still air component of the conductive heat flow entering the wall is equal to the rate of heat transferred to the incoming air mass. The maximum temperature to which the incoming air can be raised is the drywall-insulation interface temperature so that, even in the idealized model, heat must be purchased to heat this air to room temperature.

The equation for optimum dynamic airflow rate is:

$$q = (k/(p*c_p))*A/d \tag{1}$$

where:

q = optimum dynamic airflow rate, m^3/s
k = coefficient of thermal conductivity for still air, 0.025 $W/m\cdot{}^\circ K$
p = density of air, kg/m^3
c_p = specific heat of dry air, $J/kg\cdot{}^\circ K$
A = dynamic wall area, m^2
d = thickness of insulating area, m

The optimum rate indicates the transition point at which the law of diminishing returns sets in, that is, the flow at which the interior wall surface begins to cool down as it provides the heat necessary to warm up the incoming air.

With a dynamic wall area of 138 m^2 and a wall thickness of 127 mm, the optimum airflow rate was calculated to be approximately 22 L/s.

4.2.4 Actual Dynamic Air Flows

Dynamic operation of the demonstration house was achieved through depressurization caused by the central exhaust fan. Based on the

Canadian Standards Association (CSA) Preliminary Standard F326.1, *Residential Mechanical Ventilation Requirements*, the minimum ventilation air required for the house is 75 L/s of continuous supply and exhaust with an intermittent exhaust capacity of 125 L/s. The maximum average exhaust flow rate that the fan in the demonstration house could achieve was approximately 72 L/s, a rate that is equivalent to 0.33 ACH. As a result, the performance of the dynamic wall could not be investigated at higher ventilation rates.

Measurements of dynamic air flow indicated that the total air flow through the 138 m^2 of dynamic wall was approximately 20 L/s when the total ventilation rate was 65 L/s. At 72 L/s, therefore, it was estimated that the dynamic airflow rate was approximately 23 L/s. Measured flows account only for the dynamic flow through the inlet holes in the drywall and do not include other sources of dynamic infiltration. However, since air can enter the stud cavity only by slow infiltration through the exterior Tyvek membrane, at least 23 L/s of the infiltrating air participates in the dynamic wall process.

These results suggest that dynamic wall area in larger houses should be increased by including the attic insulation since, as the house becomes larger, the ratio of wall surface area to volume of house decreases. However, some creative design would be required to keep construction costs reasonable, and it could be difficult to achieve the negative pressure necessary to ensure dynamic air flow through the ceiling insulation.

4.3 BUILDING ENVELOPE PRESSURES

4.3.1 Effects of Different Exhaust Flow Rates on Building Envelope Pressures

Envelope airtightness test results indicated that, when the house was depressurized to 50 Pa, the air change rate was 0.93 ACH before the dynamic air inlet holes were drilled and 1.31 ACH after. These measurements were taken with the supply and combustion air ducts sealed at the weatherhoods. Analysis of these results (Appendix B) predicted that, at a total ventilation rate of 65 L/s and a dynamic air flow of 23 L/s, the pressure drop across the envelope would be approximately 5 Pa.

The computerized monitoring system measured the pressure differential across the building envelope at mid-wall height on each floor. With the house sealed, building envelope pressures were measured at different exhaust flow rates. Monthly summaries of the daily averaged pressure differentials are included in Appendix C. Averages taken from the daily summaries for data sets 1 through 8 are presented in Table 3. Negative pressure values indicate that the house is negatively pressurized.

Data Sets 1-4

The measurements in Data Sets 1-4 indicate the approximate levels of depressurization at which the dynamic house would have to operate to meet CSA F326 continuous ventilation requirements. The average ceiling pressure differential of 0.1 Pa indicates that the neutral pressure plane is just above the level of the ceiling so that the entire house is depressurized. The average pressure differential across the upstairs walls was approximately 4 Pa and across the main floor walls, 6 Pa. The basement pressure differential, measured on only one wall, was approximately 10 Pa. The pressure differentials between floors were caused by the stack effect and compared well to calculated values.

With the house operating at a negative pressure, the inflow of dynamic air virtually eliminates the potential for problems due to interstitial wall moisture. Two other potential problems in a house operating under negative pressure are high radon levels and backdrafting. Radon concentration measurements (Section 4.5.2) indicated that there was no need for concern about radon in this particular house (radon is generally not a concern in Alberta). Computer monitoring of carbon monoxide levels suggested that fireplace backdrafting had not occurred. The use of a direct vent

Table 3

BUILDING ENVELOPE PRESSURES

Date	Data Set	Outdoor Temp (°C)	Wind Speed (km/h)	Mode	Exhaust Flow (L/s)	Exhaust Rate (ACH)	Ceiling (Pa)*	Second Floor (Pa)*	Std Dev (Pa)	Main Floor (Pa)*	Std Dev (Pa)
DE 07-15	1	-6.6	11	Dynamic	71.8	0.32	-0.1	-3.9	2.0	-6.3	1.3
JA 19-28	2	-5.3	11	Dynamic	71.5	0.32	0	-3.9	1.3	-6.2	0.5
FE 18-28	3	-1.0	10	Dynamic	72.3	0.32	-0.1	-3.6	1.4	-5.5	0.6
MR 01-29	4	0.6	10	Dynamic	72.2	0.32	-0.1	-4.6	1.4	-6.1	0.8
JA 03-07	5	-6.6	10	Dynamic	52.8	0.23	0	-2.3	0.6	-5.5	0.3
JA 09-12	6	-3.5	12	Dynamic	63.7	0.28	0.4	-0.4	2.5	-1.8	0.7
DE 18-31	7	-6.6	11	Static	0	0	0.5	1.9	1.5	-1.5	0.7
FE 03-14	8	-9.1	10	Static	0	0	0.6	2.8	1.6	-0.2	0.9

Data Sets 1-5 - Exhaust system operating, fresh air and combustion air ducts blocked.

Data Set 6 - Exhaust system operating, fresh air and combustion air ducts open.

Data Sets 7,8 - Exhaust system off, fresh air and combustion air ducts open.

* Average pressure differentials ($P_{in} - P_{out}$).

condensing furnace and an induced draft domestic hot water heater safeguarded these appliances against backdrafting.

Data Set 5

With the exhaust system operating at 53 L/s or 0.23 ACH, the data indicated that the house was still depressurized and that the neutral pressure plane was now at ceiling level. Although these pressure differentials suggest that the house could operate successfully as a dynamic wall house, this exhaust flow rate would not meet CSA F326 continuous ventilation requirements.

Data Set 6

With the fresh air and combustion air ducts open so that some ventilation air was being drawn in through these ducts as well as through dynamic walls, the neutral pressure plane dropped below the level of the ceiling and negative indoor pressures were lower, suggesting that the supply air duct should be permanently blocked in order for this dynamic wall house to operate properly.

Data Sets 7-8

When the house was operating in a conventional manner, with the exhaust fan off and the fresh air and combustion air ducts open, the neutral pressure plane was located inside the house, and the upper floor was generally positively pressurized due to the stack effect.

4.3.2 Effects of Wind Speed and Direction on Building Envelope Pressures

Analysis of dynamic airflow measurements indicated that, under windy conditions, significant increases in flow occurred on the windward side of the house. Timusk[2] found that the combined wind and stack effects were not sufficient to reverse flow through leeward dynamic holes upstairs, but that there was a definite wind effect on the flow through individual walls. His work on flow-pressure relationships through Tyvek indicated a linear relationship, which could be expected in a system governed by friction.

Wind speed and direction, and the pressure differential across one stud cavity in each wall of each floor were monitored continuously. The airflow data for each of these cavities combined with monitored wind and pressure data are presented in Table 4.

As previously discussed, the volume of ventilation air entering the house through the dynamic air inlets can vary significantly with changes in pressure across the building envelope. The hourly data for three different days is presented in Figures 17 to 22. Table 5 shows the daily averaged pressure differentials for each wall on each floor taken from the monthly summaries in Appendix C. The data indicates that the hourly averaged pressure differential across a particular wall can vary significantly throughout the day.

December 13 (Figures 17 and 18)

The data in Table 5 indicates that the average wind speed for this day was 6 km/h, predominantly from the southwest. Although wind speeds were generally light, the hourly pressure data presented in Figures 17 and 18 clearly show how sensitive the envelope pressures are to wind direction and velocity changes. Wind direction and relative velocity could be easily determined by an examination of pressure data.

Figure 17 shows pressure data for the second floor. The average wall pressure differential was 1.6 Pa, ranging from 1.9 Pa on the south (windward) wall, to 1.4 Pa on the north (leeward) wall. Figure 18 shows pressure data for the main floor. The average pressure differential was 4.1 Pa, ranging from 5.4 Pa on the windward wall to 3.1 Pa on the leeward wall. The differences between floors were due mainly to the stack effect.

Figure 17 shows how dramatically wind speed and direction can affect the pressure differential across the wall. The wind

Table 4

EFFECT OF WIND ON DYNAMIC AIR FLOW

Date	September 5		September 8		October 3	
Wind Speed	11 km/h		17 km/h		11 km/h	
Direction	N		N		SSW	
Location	Flow (L/s)	Press (Pa)	Flow (L/s)	Press (Pa)	Flow (L/s)	Press (Pa)
Second-N	0.278	8.7	0.334	13.3	0.244	2.7
Second-E	0.141	5.4	0.090	6.1	0.167	1.4
Second-S	0.051	4.5	0.090	3.8	0.141	5.6
Second-W	0.219	4.8	n/a	4.3	0.188	5.4
Main-N	0.064	5.8	0.090	7.3	0.026	5.1
Main-E	0.051	5.8	n/a	5.2	0.103	4.0
Main-S	0.136	5.9	n/a	5.4	0.244	8.7
Main-W	0.231	5.5	0.159	6.2	0.188	4.4

Table 5

AVERAGE PRESSURE DIFFERENTIALS BETWEEN FLOORS

Date	Wind Speed (km/h)	Wind Dir	Exhaust Rate (ACH)	Floor	Building Envelope Pressure Differential				
					South (Pa)	East (Pa)	North (Pa)	West (Pa)	Avg (Pa)
DE 13	6	SW,W	0.32	Second	1.9	1.1	1.4	1.8	1.6
				Main	5.4	3.8	3.1	4.1	4.1
DE 14	16	S,SE	0.32	Second	10.0	2.6	6.3	4.6	5.9
				Main	13.0	5.1	6.6	6.0	7.7
JA 26	14	N,NW	0.32	Second	1.5	2.9	8.9	1.6	3.7
				Main	6.9	6.3	7.8	5.5	6.6

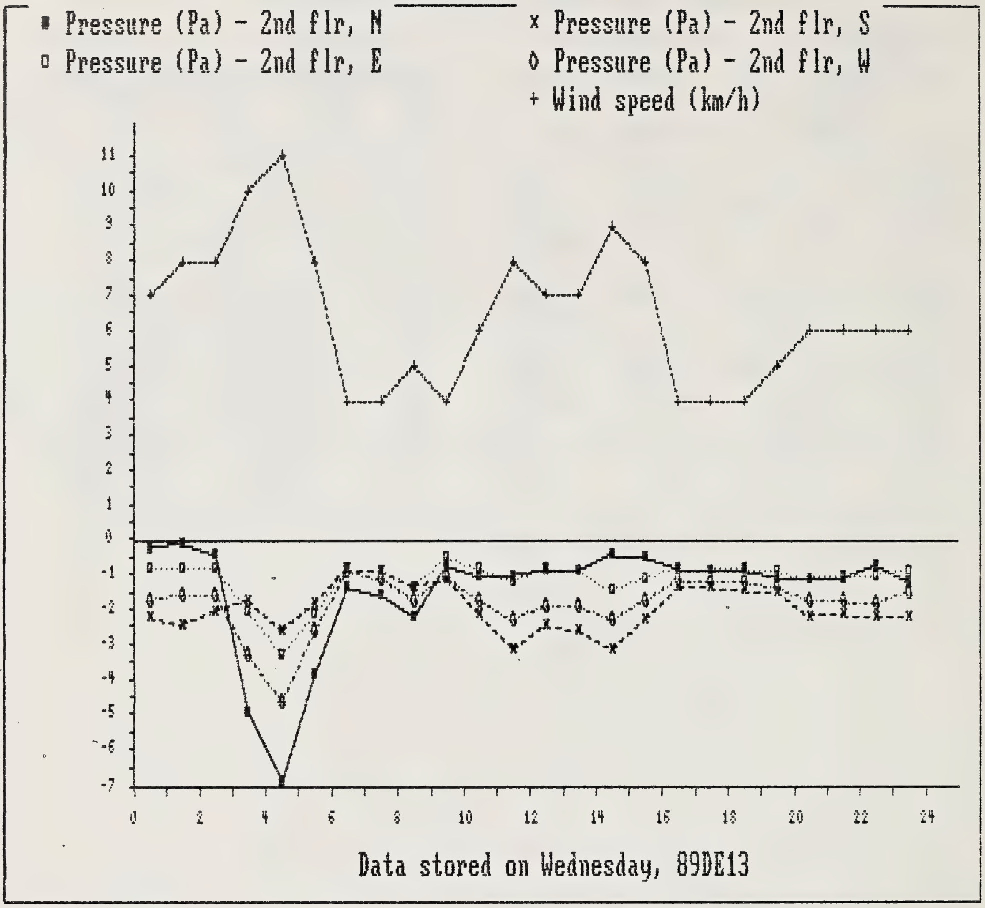


Figure 17: Envelope Pressure Differentials - 2nd Floor

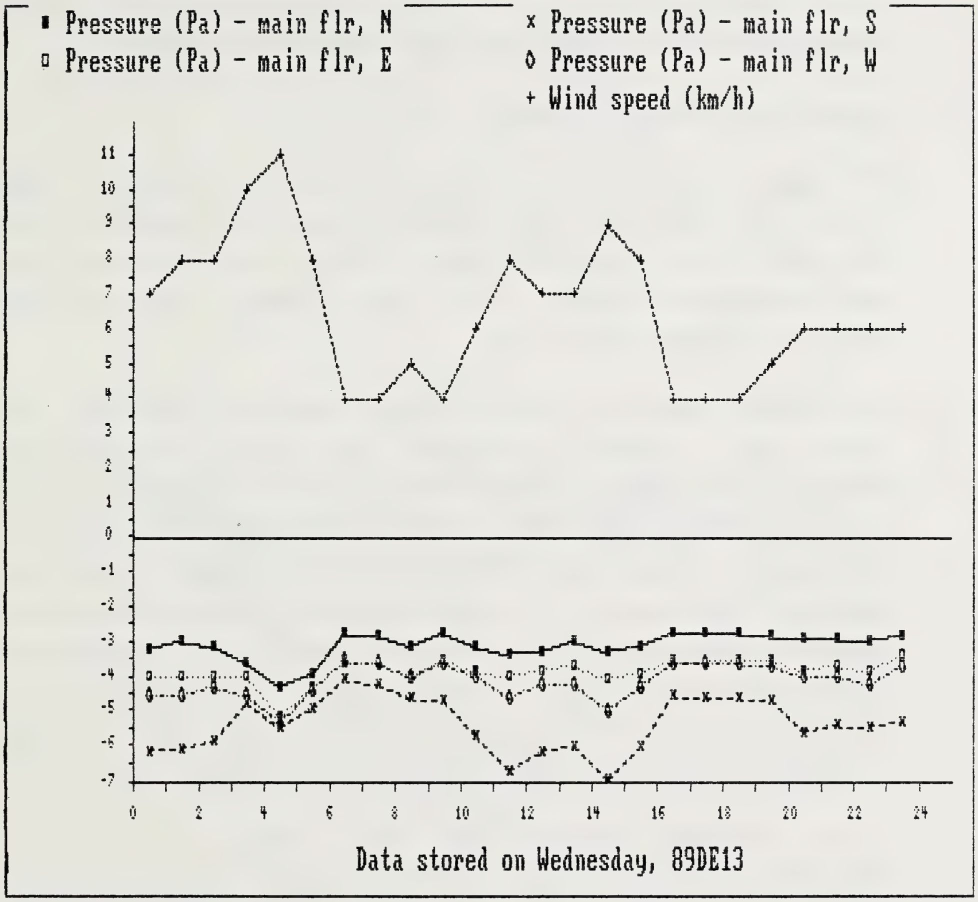


Figure 18: Envelope Pressure Differentials - Main Floor

changed from the southwest to the northwest in the 2-hour period between 02:00 and 05:00, causing the pressure differential across the north wall to increase from approximately 0 to 7 Pa.

December 14 (Figures 19 and 20)

Wind speeds increased significantly on December 14 (Table 5). The average wind speed for this day was 16 km/h, predominantly from the south. The effects of higher winds on wall pressures were less predictable because of the wind dynamics caused by such factors as neighbouring houses.

Second-floor pressure differentials are shown in Figure 19. The average wall pressure differential was 5.9 Pa, ranging from 10.0 Pa on the south (windward) wall to 2.6 Pa on the east wall. During the 3-hour period from 11:00 to 14:00, there was a positive pressure on the east wall relative to the outside. Under this condition, no dynamic air would be flowing across this wall. Figure 20 shows main floor pressure data. The average wall pressure differential was 7.7 Pa, ranging from 13.0 Pa on the windward wall to 5.1 Pa on the east wall. As expected, the range of pressures was greater with higher wind velocities.

It is important to note also that, although the pressure differential across a wall may occasionally approach zero or become slightly positive on windy days, pressures are generally negative and, when operation is in the dynamic mode, the house is not subjected to uncontrolled exfiltration.

January 26 (Figures 21 and 22)

The average wind speed for January 26 was 14 km/h, predominantly from the north. This day was chosen to illustrate wall pressure data when the house was subjected to a north wind.

Second-floor pressure data is shown in Figure 21. The average wall pressure differential was 3.7 Pa, ranging from 8.9 Pa on the north, or windward wall, to 1.6 Pa on the west wall. Although there was a strong north wind blowing, the south and west wall

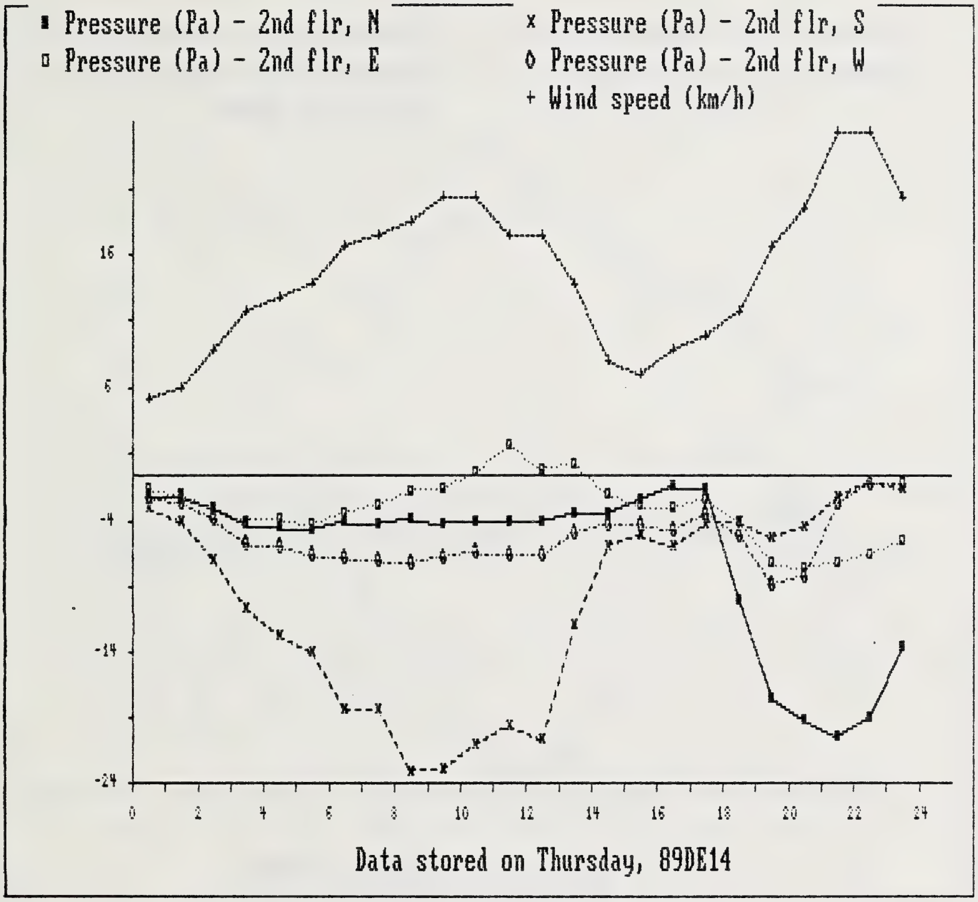


Figure 19: Envelope Pressure Differentials - 2nd Floor

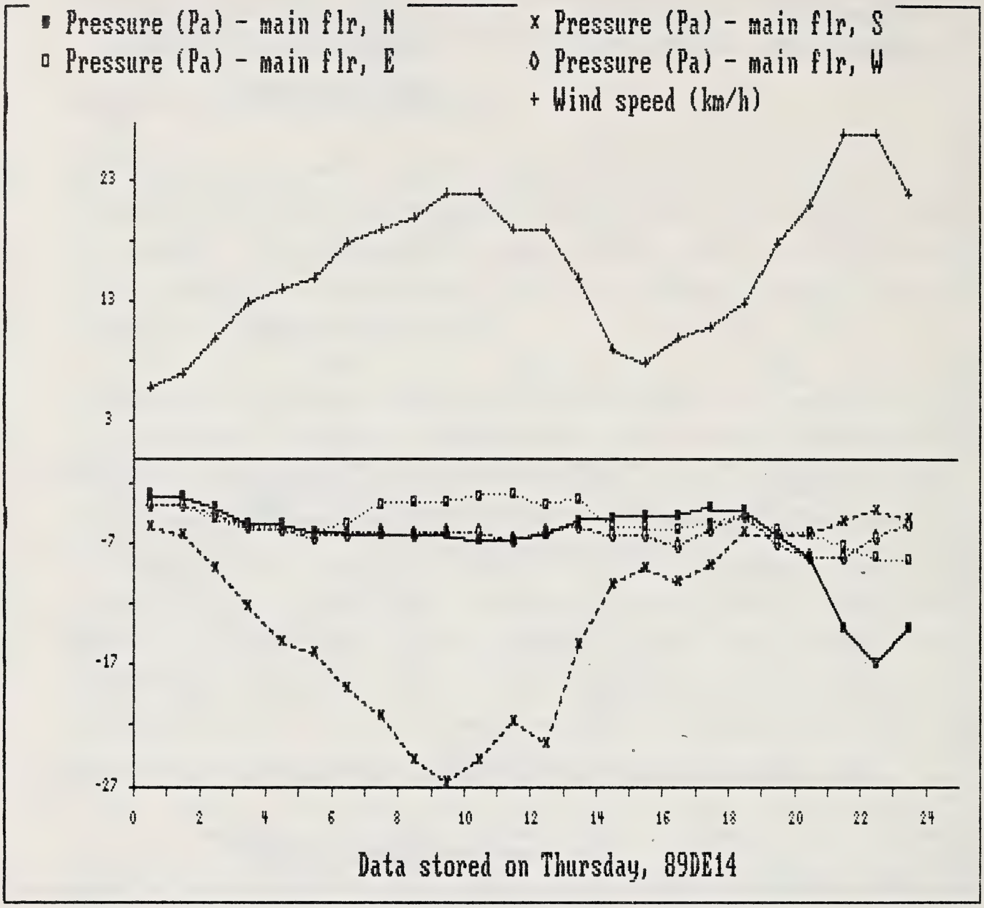


Figure 20: Envelope Pressure Differentials - Main Floor

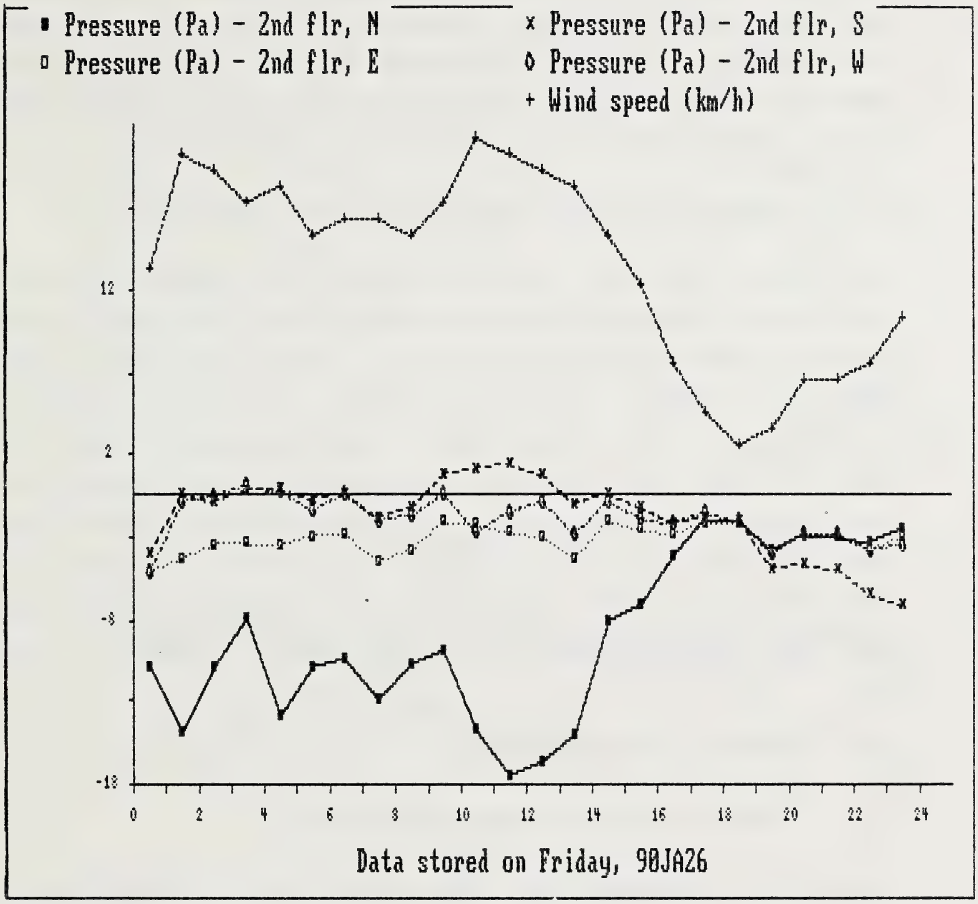


Figure 21: Envelope Pressure Differentials - 2nd Floor

pressures were either very close to zero, or positive relative to outdoors. From 09:00 to 13:00, there was a positive pressure on the south wall. Under this condition, no dynamic air would be flowing across this wall. In Figure 22, which shows main floor pressure data, the average wall pressure was 6.6 Pa, ranging from 7.8 Pa on the windward wall to 5.5 Pa on the west wall.

4.3.3 Effects of Varying Pressures on Indoor Air Quality

The hourly and daily averaged pressure data gathered by the computer and the dynamic flow analysis indicates that ventilation air is not supplied equally across all walls of the house. This does not, however, appear to affect indoor air quality significantly. The results of the perfluorocarbon passive air tests indicated that the total flow in and out of the second floor was 1170 m^3/h, a flow equivalent to 4.0 ACH, while the flow in and out of the main floor was 581 m^3/h, or 2.3 ACH. The reason for this difference appears to be the mixing between floors that resulted from the continuous low speed operation of the furnace fan.

4.4 DYNAMIC AIR TEMPERATURES

4.4.1 Building Envelope Temperature Profile

Timusk (1987) proposes that, under conditions of constant indoor and outdoor temperatures, negligible solar radiation, and air flows through the dynamic wall at a rate equal to or less than the optimum rate, the temperature gradient of a dynamic wall will be the same as a conventional or "static" wall. The incoming air will absorb the heat being transferred through the wall by conduction and act as a 100 per cent efficient heat exchanger. The temperature of the incoming air will be raised from the outdoor temperature to the temperature of the drywall-insulation interface, and there will be no cooling of the interior wall surface.

When incoming airflow rates are greater than the optimum rate, the

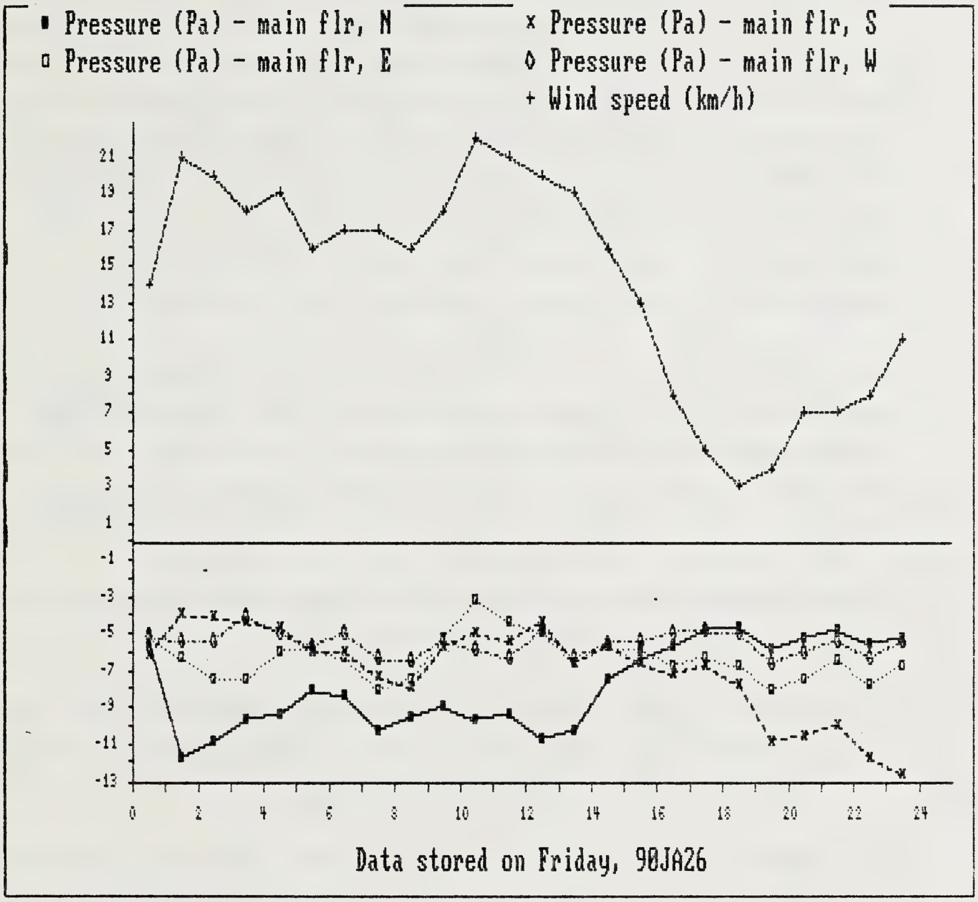


Figure 22: Envelope Pressure Differentials - Main Floor

heat being transferred through the static air within the wall by conduction will not be sufficient to heat up this increased flow. As a result, the incoming air will begin to absorb the radiant heat being transferred through the wall, causing a cooling of the interior wall surface. If the flow rate is high enough, all of the radiant heat will be captured and the temperature gradient at the exterior surface of the insulation will become horizontal. Under these conditions, the maximum amount of energy will be conserved, but the interior wall surface will be cooled to a temperature that may not be acceptable to the occupants.

Wall temperatures on the second floor were measured with 24 thermocouples in a dynamic stud cavity in the south wall and 6 thermocouples in dynamic cavities in each of the north, east and west walls. The location of each of these sensors is detailed in Table 6.

Averaged hourly data measured in the south wall stud cavity is presented in Table 7 for four different days:

(1) December 27 was representative of static operation (the flow of dynamic air was zero). This would be the condition typically found in conventional housing.

(2) January 6 was representative of dynamic operation when the building envelope was subjected to a pressure differential of 3.8 Pa. Data presented in pressure differential tables in Appendix C suggests that at this pressure the incoming dynamic airflow rate would be less than the optimum rate discussed in Section 4.2.1.

(3) January 12 was representative of dynamic operation at an airflow rate similar to that of January 6 but at lower outdoor temperatures.

(4) December 10 was representative of dynamic operation with the exhaust fan running at maximum capacity, at very cold outdoor temperatures.

Table 6

SOUTH WALL TEMPERATURE PROFILE

Date	Press Diff (Pa)	Temp Out (°C)	Temp In (°C)	Location of Sensors	Under Siding (°C)	Glasc/ Batt (°C)	Mid Batt (°C)	Batt/ Drywall (°C)
December 27 03:00	0.3	3.6	21.3	Top	4.3	10.2	18.2	19.9
				Middle	3.6	10.0	16.8	19.3
				Bottom	3.5	10.2	15.3	19.6
January 6 07:00	-3.8	3.1	22.1	Top	3.8	9.3	17.8	19.7
				Middle	2.8	8.6	16.0	19.0
				Bottom	2.4	8.5	14.1	18.9
January 12 05:00	-3.6	-4.7	23.5	Top	-4.0	4.8	17.9	20.8
				Middle	-5.2	4.1	15.2	19.8
				Bottom	-5.7	4.5	12.7	20.0
December 10 22:00	-4.7	-17.9	22.2	Top	-16.6	-3.7	14.0	17.8
				Middle	-18.5	-5.1	10.4	16.2
				Bottom	-19.7	-5.1	6.0	15.9

Table 7

DECREASE IN DRYWALL SURFACE TEMPERATURE

Date	Press Diff (Pa)	Temp Out (°C)	Temp In (°C)	Batt/ Drywall (°C)	In/Dry Diff (°C)	Dyna Temp (°C)
December 27	0.3	3.6	21.3	19.6	1.7	n/a
January 6	-3.8	3.1	22.1	19.2	2.9	14.2
January 12	-3.6	-4.7	23.5	20.2	3.3	13.9
December 10	-4.7	-17.9	22.2	16.6	5.6	7.4

This information is also presented graphically in Figure 23. The three sections in this figure depict the temperature profile one foot down from the top of the wall, at the middle of the wall, and one foot up from the bottom of the wall.

Hourly averaged data stored at 03:00 on December 27 and 07:00 on January 6 represents conditions when temperatures were approximately the same and solar radiation was negligible. The temperature profile for these days (Figure 23) illustrates that, as predicted by the theory, the dynamic wall profile for January 6 is roughly the same as the static, or conventional wall profile for December 27. The temperature profiles for January 12 and December 10 illustrate that, although colder outdoor temperatures alter the slope of the profile, its shape remains the same.

The data in Table 7 also indicates a decrease in the temperature at the interface of the drywall and batt insulation as the outdoor temperature decreases. The summary tables in Appendix D show that the dynamic air entering the house is only tempered to approximately 75% of the indoor-outdoor temperature differential. (This will be discussed in detail in Section 4.4.3). The heat being transferred through the wall by conduction was not sufficient to heat the incoming air to the temperature of the drywall-insulation interface. The cooler incoming air, therefore, absorbed radiant heat from the drywall surface, resulting in cooler drywall temperatures. The data in Table 7 indicates that the temperature differential across the drywall increased from 1.7° on December 27, when there was no incoming air and the outdoor temperature was 3.6°C, to 5.6° on December 10, when the pressure differential across the wall was 4.7 Pa and outdoor temperature was -17.9°C. Based on the Dynamic Wall Theory, this degree of cooling suggests that dynamic flow rates were greater than optimum. Wall surface temperatures inside the house were not measured, so the decrease in temperature is not known.

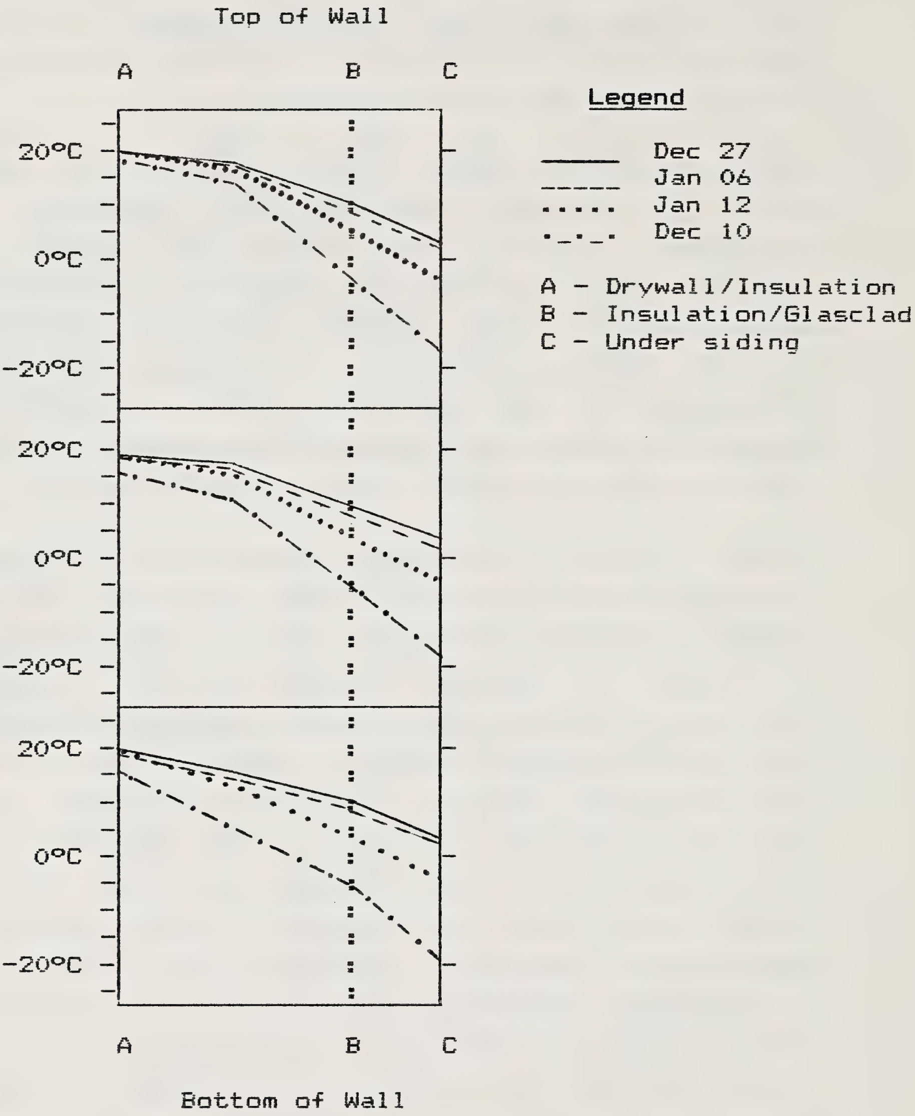


Figure 23: South Wall Temperature Profile

4.4.2 Comparison with Fibreboard Cavity

A "fibreboard cavity" was constructed on the south wall of the second floor using expanded studs and fibreboard exterior sheathing rather than Glasclad. This cavity was instrumented in the same manner as the "Glasclad cavity" described in the preceding section.

The fibreboard cavity was monitored from March 17-30. The results have not been analyzed in detail but are presented as a basis for discussion for interested individuals (Table 8). The airflow rate through the dynamic hole in the fibreboard cavity was approximately 0.052 L/s while the flow through the Glasclad cavity was approximately 0.192 L/s. At these flows, the dynamic air temperature from the fibreboard cavity was typically lower than the temperature from the Glasclad cavity. From the data presented in Table 8, it would appear that the fibreboard cavity does not perform as well as the Glasclad cavity.

4.4.3 Dynamic Air Thermal Characteristics

The temperature of the dynamic air entering the house is determined by the dynamic airflow rate through the wall which, in turn, is determined by the pressure differential across the wall. The pressure differential is governed by the amount of air that is exhausted from the house, the stack effect within the house, and the forces exerted by the wind on the building envelope. Optimum and actual dynamic airflow rates were discussed in Section 4.2, and the pressures resulting from different exhaust flow rates and varying wind speeds, in Section 4.3.

Monitors at eight locations in the demonstration house measured the temperature of the air entering the house through each dynamic wall on each floor. The daily averaged temperature data is presented as monthly summaries in Appendix D. These summaries also include individual room and floor temperatures.

For analysis of the temperature differential between the dynamic

Table 8

COMPARISON OF GLASCLAD AND FIBREBOARD CAVITIES

Wall Location	Glasclad Cavity (°C)	Fibreboard Cavity (°C)	Glasclad Cavity (°C)	Fibreboard Cavity (°C)	Glasclad Cavity (°C)	Fibreboard Cavity (°C)
	March 22		March 20		March 28	
Top of Wall						
Under Siding	-7.5	-7.1	-1.4	-0.9	9.2	9.4
Glas/(Fbd)/Batt	2.4	-4.7	6.6	1.2	13.4	10.5
Mid Batt	18.2	4.9	19.3	8.8	19.7	14.6
Batt/Drywl	15.8	16.7	17.3	18.0	19.2	19.2
Middle of Wall						
Under Siding	-5.0	-5.5	-2.3	-2.1	11.9	11.4
Glas(Fbd)/Batt	3.7	-2.3	5.8	0.6	15.0	13.1
Mid Batt	13.4	4.2	14.6	6.7	18.2	15.1
Batt/Drywl	17.3	16.4	18.1	17.6	19.6	19.4
Bottom of Wall						
Under Siding	-5.4	-5.7	-2.6	-2.6	12.7	11.2
Glas(Fbd)/Batt	4.8	-3.3	6.9	.0	16.4	12.5
Mid Batt	12.0	4.6	13.7	7.4	18.5	15.1
Batt/Drywl	17.9	14.9	19.2	16.6	19.9	18.7
Dynamic Air	16.6	10.5	17.0	12.9	19.8	16.3

air entering the house and room temperature, and its relationship to outdoor temperature, specific information was taken from Data Sets 1-6 (Appendix D), and the averaged temperature differentials were put into tables (Appendix E). The averaged temperature differentials for these periods, along with averaged outdoor temperatures and building envelope pressures, are presented in Table 9.

Equation (1) in Section 4.2.3 indicates that the amount of tempering of the dynamic air is independent of the actual indoor-outdoor temperature differential. It is affected, however, by the ventilation rate, which is determined by the pressure differential across the wall. The data summary in Table 9 and the daily summaries in Appendix D confirm this. The information for Data Sets 1-5 in Table 9 indicates that, although the outside temperature varies significantly, the degree of tempering remains constant at approximately 74%. The pressure differentials across the building envelope remained relatively constant during these periods, suggesting that ventilation rates were also constant. The daily summaries in Appendix D indicate that, from the coldest days in December to the mildest days in March, as long as the ventilation rate remained constant, the percentage of tempering also remained constant.

In Data Set 6, the indoor pressures increased significantly, resulting in reduced pressure differentials and a reduced flow of dynamic air. This resulted in an average tempering of 79%.

While the degree of tempering remained constant, the temperature of the dynamic air entering the house varied with the indoor-outdoor temperature differential. Table 9 also presents data for 5 days ranging from a cold day in December to a warm day in March. The temperature differential between the dynamic air entering the room and the average indoor temperature decreased as the indoor-outdoor temperature differential decreased. It is this temperature differential that results in the cooling of the interior drywall surface (Section 4.4.1).

Table 9

DYNAMIC AIR TEMPERATURE DIFFERENTIALS

Date	Data Set	Temp Outdoor	Temp Indoor	2-Flr Diff[1]	1-Flr Diff[1]	2-Flr Press[2]	1-Flr Press[2]	% Temper[3]
DE 07-15	1	-6.6	21.3	7.1	7.5	3.9	6.3	74%
JA 19-28	2	-5.3	20.3	6.7	7.7	3.9	6.2	71%
FE 18-28	3	-1.0	21.0	5.5	5.5	3.6	5.5	75%
MR 01-29	4	0.6	20.9	5.3	5.2	4.6	6.1	74%
JA 03-07	5	-6.6	21.3	6.5	7.1	2.3	5.5	75%
JA 09-12	6	-3.5	21.1	3.1	5.9	0.4	1.8	79%
December 10		-19.1	21.3	11.2	11.4	3.8	7.6	72%
January 27		-14.3	20.6	9.2	10.6	2.5	6.1	71%
February 18		-6.9	21.6	7.3	7.2	2.6	5.5	74%
March 14		0.3	22.3	4.8	5.1	4.0	6.1	76%
March 27		6.3	21.2	3.8	4.2	4.8	4.6	73%

[1] Average temperature differential between dynamic air and room air on second and main floor.

[2] Average pressure differential across all four walls of second and main floor.

[3] The portion of the total indoor-outdoor temperature differential to which the incoming dynamic air was warmed.

4.4.4 Effects of Wind Speed and Direction on Dynamic Air Temperatures

As discussed in Section 4.4.3, the temperature at which the dynamic air enters the house depends on the airflow rate, which is determined by the pressure differential across the building envelope. The effect of wind speed and direction on envelope pressures was discussed in Section 4.3.2. The effect of wind speed and direction on dynamic air temperatures can best be determined by an investigation of hourly data.

Figure 24 depicts a day with low wind speeds, predominantly from the southwest. The pressure differential across the south wall generally varied less than 2 Pa from the north wall. As a result, the dynamic air temperatures were almost identical, suggesting that similar air flows were occurring across each wall. The dynamic air temperature of the south wall was slightly less than the north wall, indicating the sensitivity of the dynamic walls to pressure differentials of even 1 to 2 Pa.

Figure 25 represents a day of much higher wind speed during which the wind changed from 14 km/h from the south at 01:00 to 22 km/h from the northwest at approximately 13:00. Prior to 13:00, the south wall was subjected to a greater pressure differential, resulting in a higher dynamic airflow rate and the lower dynamic air temperatures shown on the graph. After the wind switched direction, the north wall was subjected to the higher pressure differential and resultant lower dynamic wall temperatures.

Although the average pressure differentials across the second floor walls were lower than across the main floor walls, the data summaries in Appendix D indicate that the average dynamic air temperatures and, therefore, the average degree of tempering were not significantly different. The analysis carried out within the scope of this project was not able to explain the reason. Future investigations may address this issue.

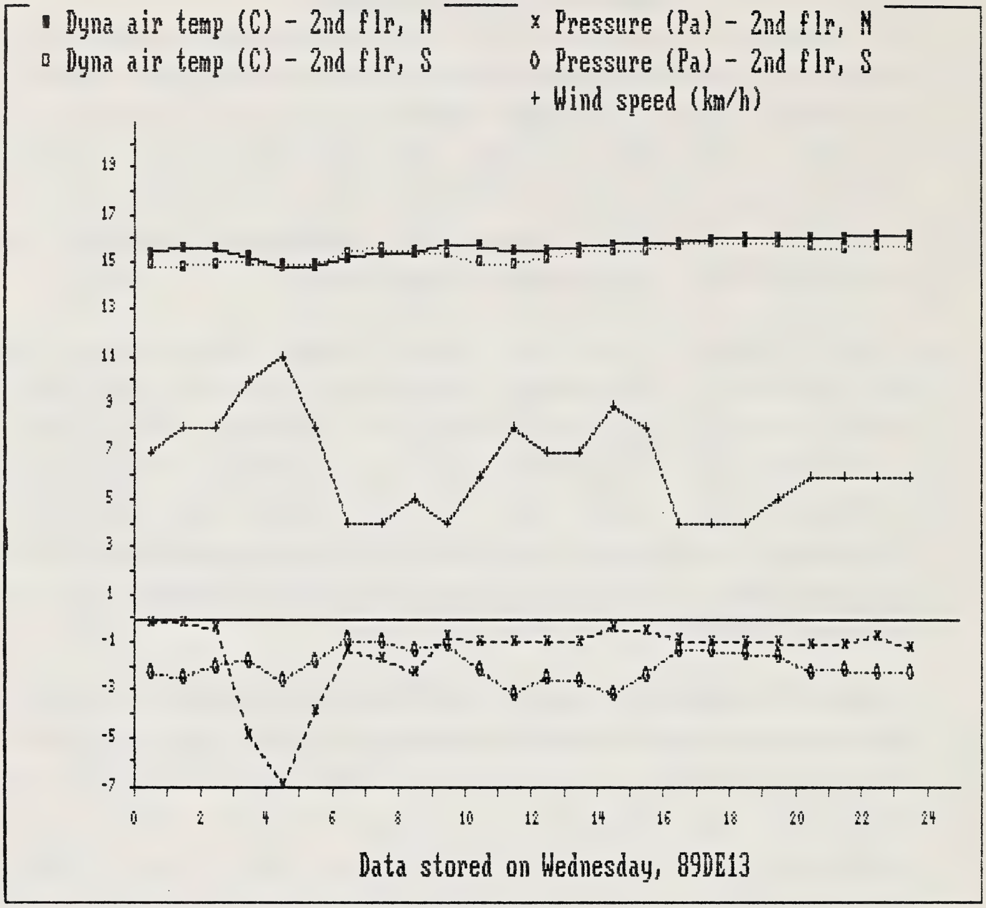


Figure 24: Effect of Pressure on Dynamic Wall Temperature

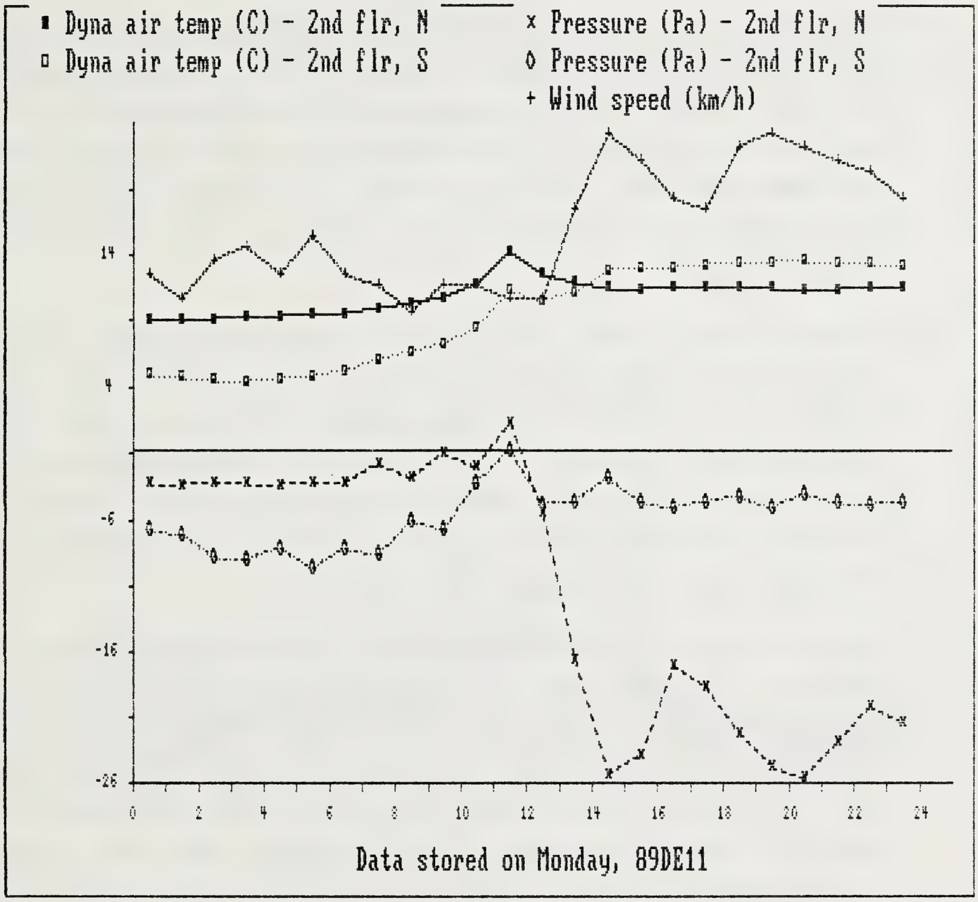


Figure 25: Effect of Pressure on Dynamic Wall Temperature

4.4.5 Effects of Solar Radiation

In a recent paper entitled *The Dynamic Wall as a Solar Collector*, Timusk (1989) compares dynamic insulation to a diode that allows solar heat to penetrate the insulation while retarding the flow of heat from the interior. The dynamic wall concept provides the opportunity for the building envelope to supplement the space heating requirements of the house by capturing significant amounts of solar energy.

Figures 26 and 27 show the temperature rise of the siding above the ambient air temperature on each wall of the second floor for December 18 and March 04, respectively. In both cases, the temperature of the siding on the south wall rose as much as 30 Celsius degrees above the ambient temperature (sol-air effect). Reflected radiation from snow cover, as well as solar radiation, helped to create this large temperature rise.

Figures 26 and 27 also show the pattern of temperatures peaking at different times on each side of the house. The first and generally smallest peak is on the east wall, which receive the morning sun; the highest peak and longest rise occurs on the south wall; the peak on the west wall is caused by the afternoon sun. Figure 28, the graph for April 16, is included to show that a peak is noticeable even on the north wall at certain times of the year.

Increased wall temperatures due to solar radiation can be significant in determining the temperature of the incoming dynamic air. Figure 29 shows that, on January 26, with daytime temperatures at -18°C, the solar radiation heating the south wall raised the temperature of the dynamic air entering the house by more than 5 Celsius degrees. Figure 30 shows that, on February 22, dynamic air temperatures were raised approximately 8 Celsius degrees and the incoming air temperature was greater than the room air temperature.

During recent research that has not yet been published, Timusk measured inside wall surface temperatures using an infrared

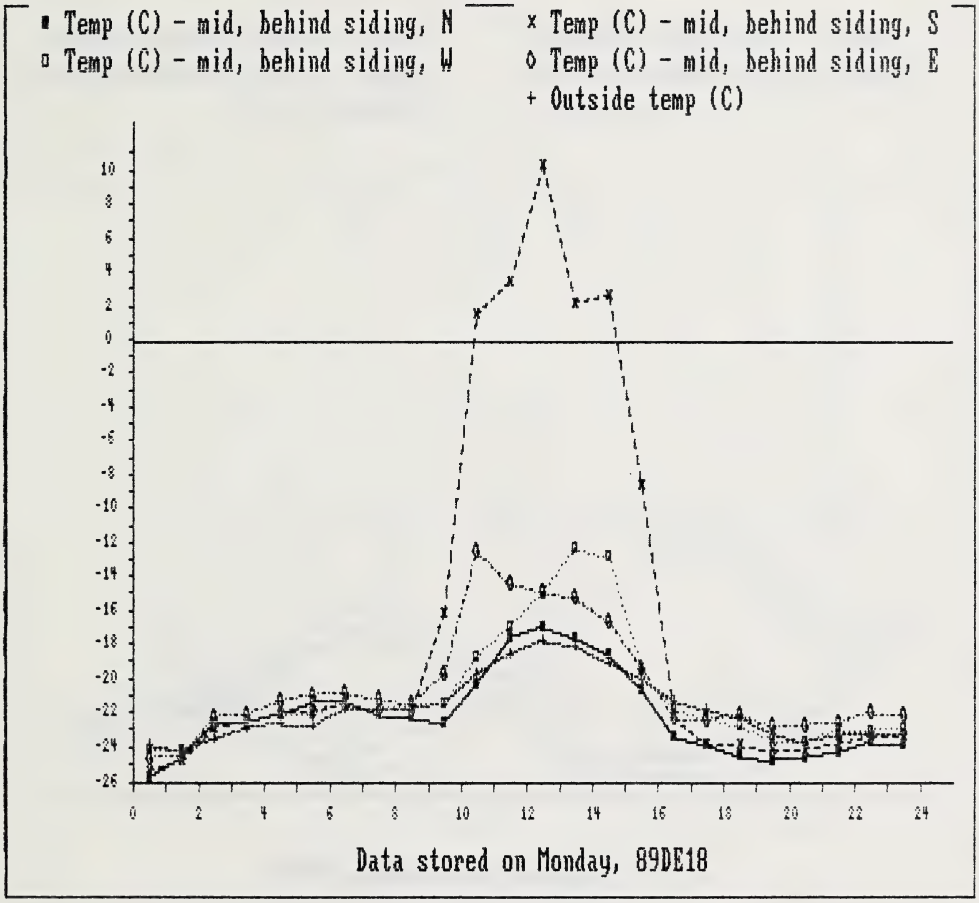


Figure 26: Sol-Air Effect - Cold Day

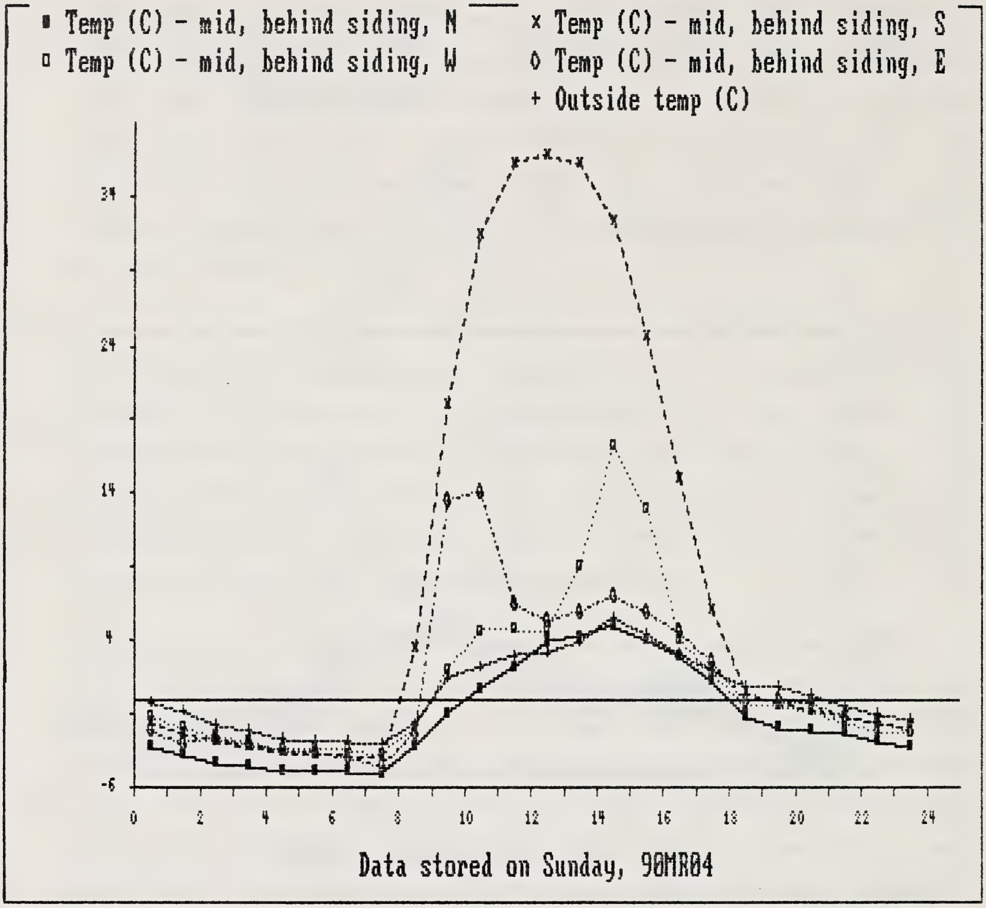


Figure 27: Sol-Air Effect - Warm Day

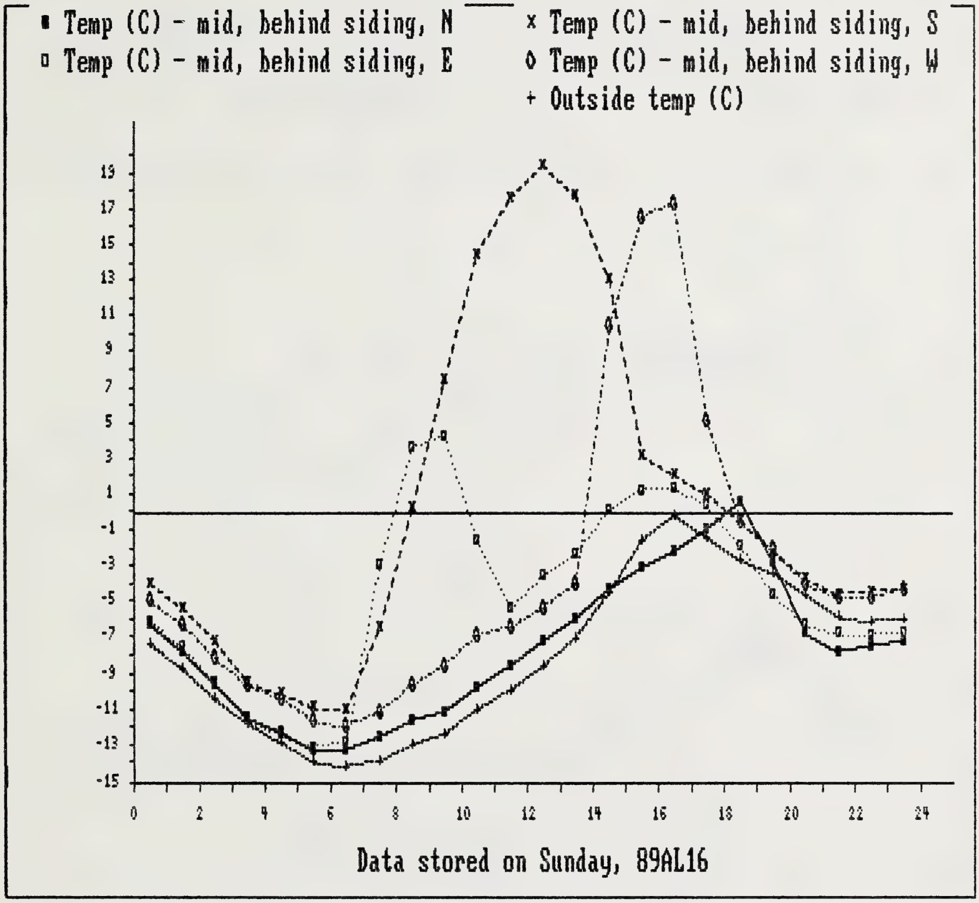


Figure 28: Sol-Air Effect on All Four Walls

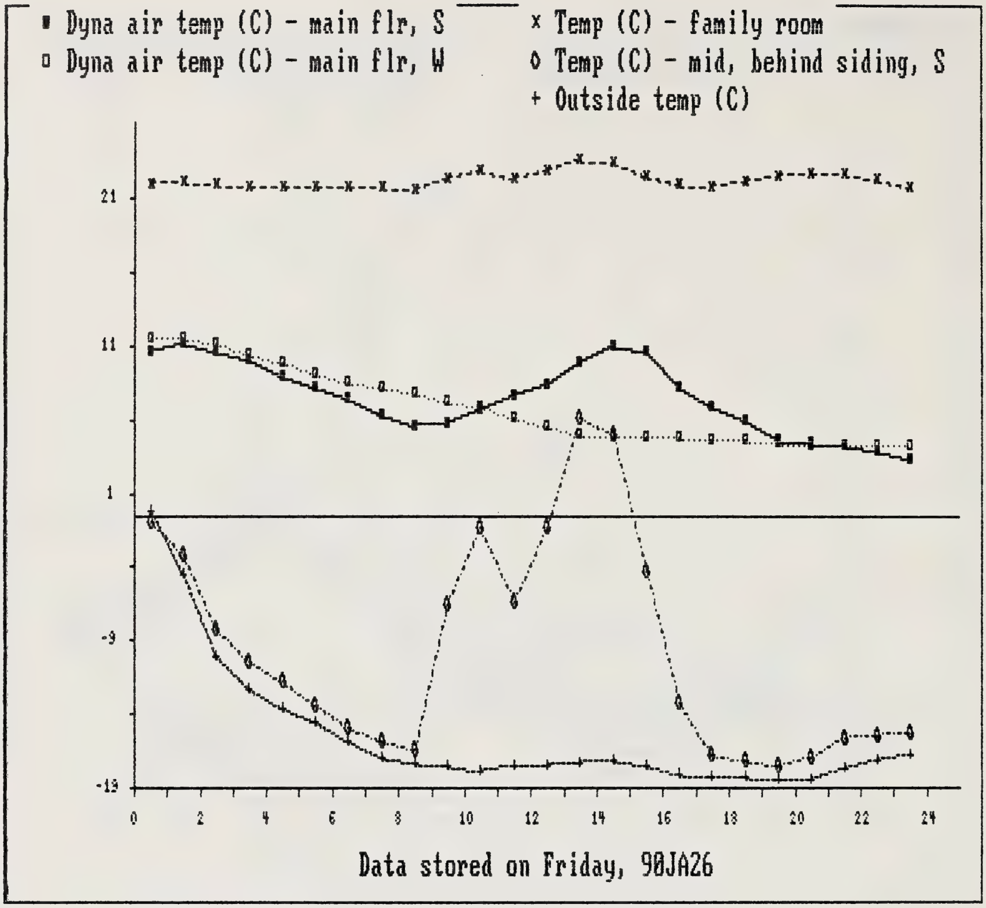


Figure 29: Sol-Air Effect on Dynamic Air Temperature

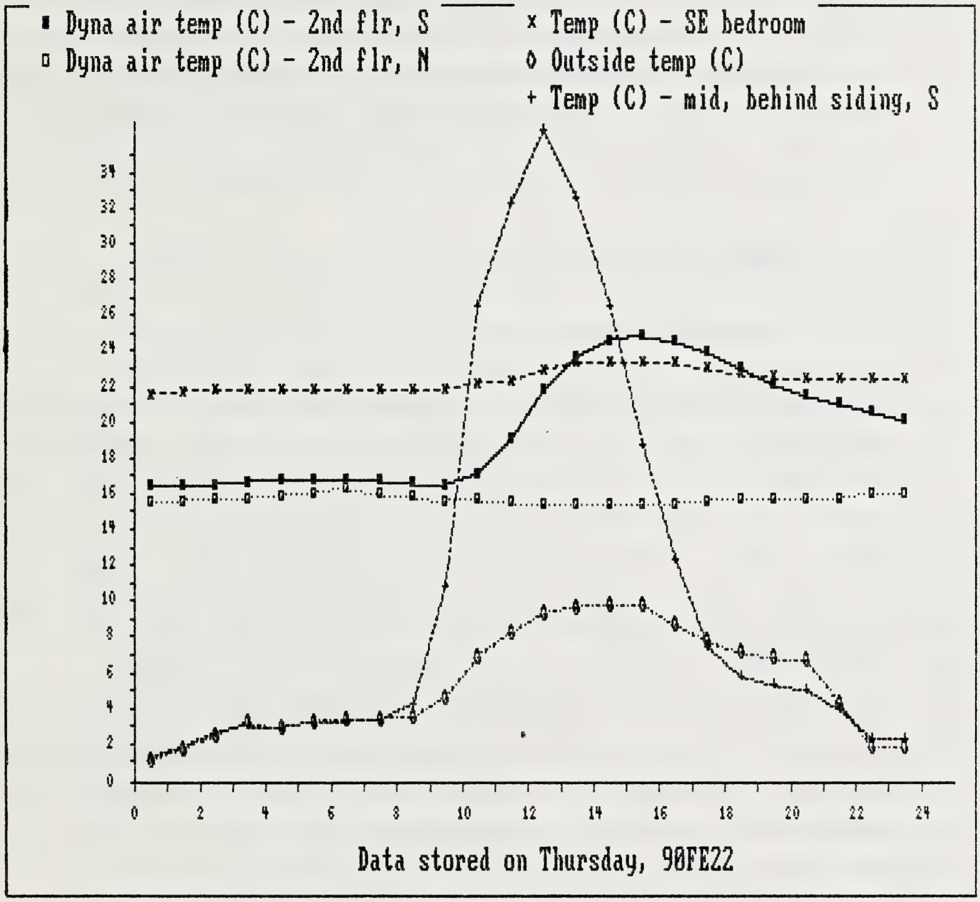


Figure 30: Sol-Air Effect on Dynamic Air Temperature

pyranometer, for both dynamic and static modes. The north wall, showed no difference between the temperatures of the interior and exterior wall surfaces. On the south wall, however, the inside surface temperature of the dynamic wall was rising both faster and higher than that for the static mode. As expected, the dynamic wall also cooled off faster, but the net effect was still positive in favour of dynamic action.

4.5 INDOOR AIR QUALITY

4.5.1 Actual Air Change Rates

Two perfluorocarbon passive air tests were done with the house unoccupied: the first, with the house ventilation system turned off, resulted in a natural ventilation rate of 0.148 ACH; the second, with the house operating in the dynamic mode and the exhaust fan set for 0.3 ACH, resulted in a total air change rate of 0.399 ACH, suggesting a natural ventilation rate of approximately 0.1 ACH.

The reduction of the natural ventilation rate to 0.10 with operation of the house in the dynamic mode follows the predicted reduction in natural ventilation rates that is caused by the reduction of stack and wind effects when a house is run in a negative pressure environment.

4.5.2 Radon

Three radon surveymeters monitored the radon levels with the exhaust fan operating at 68 L/s or 0.3 ACH, placing the house under negative pressure. The following results were obtained from the surveymeters:

Basement	0.008 WL (working levels)
Living Room	0.006 WL
Dynamic Air Opening	0.004 WL

These measurements indicate no need for concern about radon levels in this particular house. Health and Welfare Canada recommends that remedial measures be taken where the level of radon is found to exceed 800 Bq/m^3 (approximately equivalent to 0.1 WL). Other information published by the Government of Manitoba indicates that radon concentrations in the outdoor air vary from about 7 Bq/m^3 to 26 Bq/m^3 (0.0009 to 0.00325 WL).

4.5.3 Formaldehyde

Formaldehyde levels were found to be very low (Table 10). Health and Welfare Canada guidelines specify an acceptable long-term (lifetime) exposure level of 0.05 ppm and a short-term action level of 0.10 ppm. Tests done on houses registered with the R-2000 Program show formaldehyde levels of around 0.045 ppm, and a recent cross-country airtightness survey showed levels averaging 0.073 ppm in conventional houses.

4.5.4 Glass Fibres

The glass fibre concentration was measured using a radon pump near a dynamic air hole. An analysis of the filter placed in this pump detected six small fibres (less than 2 um in length). This translates into an airborne concentration of 0.0005 fibres/cc. The Ontario Ministry of Labour's 8-hour standard is 2.0 fibres/cc for the industrial environment. To date, no standards for residential occupancies have been set, but the measurement made in this house is far below the industrial standard.

4.6 HOMEOWNER COMFORT

According to the questionnaire answered by the homeowners, they were very satisfied with the comfort level of the house. No discomfort was caused by cold drafts or cold wall radiation when the house was operating in the dynamic mode. However, when operation was in the static mode (no dynamic air being drawn through the walls) with the fresh air and combustion air ducts open as in conventional housing, the homeowner commented that the house felt cooler. In the static mode with the fresh and combustion air ducts taped, humidity levels increased and

Table 10

FORMALDEHYDE READINGS

Period	Mode	Room	Formaldehyde Reading(ppm)
1	Dynamic (0.3 ACH)	Family	0.019
1	Dynamic (0.3 ACH)	Master Bdrm	0.022
2	Static[1]	Master Bdrm	0.027
3	Static[2]	Master Bdrm	0.026

[1] Fresh air and combustion air ducts open and furnace running at continuous low speed.

[2] All ducts taped.

condensation formed on the windows.

All of these findings suggest that, when this house is operating in the dynamic mode at 0.3 ACH, adequate quantities of ventilation air are being delivered to, and distributed throughout, the house.

4.7 INCREMENTAL COST ESTIMATES

For public acceptance of improvements to the energy efficiency of Alberta homes, all costs incremental to the current standards must be minimized. The costs of construction details used to implement the dynamic wall concept are analyzed in this section with a view to improvements that might be made to keep these costs to a minimum.

4.7.1 Incremental Costs of the Demonstration House as Constructed

The construction standards currently in use by the majority of Alberta builders were used as the basis for comparison in determining the incremental cost of the demonstration house. The incremental costs are shown in Table 11.

Some costs were incurred in the demonstration house that would not be incurred in future dynamic wall houses. For instance, instead of the intake fan a simple damper could be used in the fresh air line to the furnace. The damper could be closed during dynamic mode operation and opened when it was desirable to shut down the dynamic air. In a non-monitored dynamic wall house, the air passage into the house from the exterior wall cavities could be simplified by simply notching the bottom plate of the exterior wall and allowing the dynamic air to flow in under the bottom lip of the drywall and between the bottom of the baseboard and the carpet. In a production house, the window jamb widths would be planned in advance and ordered to suit the variations in wall thickness.

Table 11

SUMMARY OF INCREMENTAL COSTS

Building Standard	Incremental Cost
Demonstration house built to conventional standards	0
Demonstration house as constructed	$4245
R-2000 standard: typical R-2000 methods	$3960 to $4460
R-2000 standard: dynamic wall concept (ventilation heat recovery efficiency of 25 to 50%)	$5045 to $5245

Elimination of the associated costs would provide a more realistic figure for evaluation of the incremental costs of the demonstration house against other alternative designs such as the R-2000 standard. This would result in the following costs:

Total demonstration house costs (Appendix F)	$4945.00
Elimination of the air intake fan	<200.00>
Elimination of the drywall holes and baseboard application	<300.00>
Elimination of the need for special work on window jambs	<200.00>

Incremental costs of demonstration house as constructed	$4245.00
	=======

Because the R-2000 program has developed a consistent standard, the incremental cost of the demonstration house was compared to the cost of upgrading the standard house to the R-2000 standard, first using configurations that would typically be used, and then using the dynamic wall demonstration house as a base and upgrading it to meet the R-2000 requirements. A cost comparison of the demonstration house and the R-2000 standard house is contained in Appendix F.

4.7.2 Energy Performance of the Demonstration House

Energy efficiency is a benchmark used by home buyers to value a house. The HOT-2000 Energy Analysis Program, which is used by the R-2000 Program to predict energy consumption, was applied to the demonstration house to determine its energy efficiency.

According to the HOT-2000 estimate, the demonstration house, if built to typical Alberta construction standards (2 x 6 walls), would have an estimated annual energy consumption of 238 gigajoules (GJ), or approximately double the R-2000 target of 117 GJ. In this analysis, a natural ventilation rate of 0.40 ACH was assumed to be a reasonable estimate of the total air change that would occur in a conventionally built house in Edmonton. The energy consumption would be higher if minimum insulation levels specified by the National Building Code (2 x 4 walls) were used or if a higher natural ventilation rate (typical of much of the new housing in Canada) were assumed.

Assuming an efficiency of 50% of ventilation air heat recovery, the HOT-2000 estimate of energy consumption in the dynamic wall demonstration house, as built, was 132 GJ, or 106 GJ less than that for the same house built to conventional standards. Using an efficiency of 25% the predicted energy consumption was 146 GJ or 92 GJ less than for the conventional house.

Considering the case of 50% ventilation efficiency and current (Alberta) natural gas rates of $2.35/GJ, the savings resulting from the estimated energy performance would be approximately $250 per year. Continuous operation of the furnace and exhaust fans for ventilation would not be required, resulting in additional (electrical) energy savings of approximately $120. Thus, the total energy savings would be in the order of $370 per year.

5.0 CONCLUSIONS

The purpose of this project was to construct a demonstration house using construction details consistent with the dynamic wall concept and then to test the operation of the house. It is clear that the dynamic wall envelope and the required negatively pressurized operating environment can be constructed to suit the Alberta climate.

The conclusions are grouped into three categories: physical, operational, and economic.

In the physical category, the following five conclusions describe the dependencies and characteristics of incoming dynamic air:

(1) The rate of air flow through the dynamic wall cavity is directly proportional to the pressure differential across the cavity.

(2) The pressure differential across the dynamic wall is, in turn, directly proportional to fan speed, but is also affected by wind speed, wind direction, and indoor-outdoor temperature differentials.

(3) With indoor and outdoor temperatures constant, the shape of the temperature profile of the wall cavity is approximately the same for both static and dynamic modes of operation.

(4) The degree of tempering of dynamic air is inversely proportional to the ventilation rate which, in turn, is a function of the pressure differential across the wall. The fact that 100% tempering was not achieved, even at significantly reduced ventilation rates, leads to the conclusion that other heat transfer mechanisms, not detected during this project, affect the tempering process.

(5) The temperature of incoming dynamic air is significantly affected by solar radiation. Dynamic air temperatures can be increased even at walls that do not have a south exposure.

In the operational category, the following three conclusions describe the effects of the dynamic wall system on the "livability" of the dwelling:

(1) The dynamic wall system is capable of ensuring that adequate quantities of ventilation air are supplied to the dwelling unit.

(2) The quality of indoor air is not compromised by the dynamic wall system.

(3) Despite the absorption of radiant heat from the wall surface by incoming dynamic air at high indoor-outdoor temperature differentials, occupant comfort is not adversely affected by the dynamic wall system.

In the economic category, the calculated annual energy cost saving of $370 (at Alberta rates) does not compare favorably to the initial incremental cost of approximately $4200.

Section 6.3 discusses some possibilities that could significantly improve the cost-effectiveness ratio.

6.0 RECOMMENDATIONS FOR FUTURE STUDY

The dynamic wall concept has proven workable in the Alberta environment. Future studies should be directed towards both technical and practical means to reduce the incremental cost while improving, or at least maintaining, the performance level of the system.

6.1 TECHNICAL CONSIDERATIONS

Additional research is necessary to provide a better understanding of the heat transfer mechanisms within the dynamic wall so that wall performance and the tempering of incoming air can be maximized.

It is not clear at this time that the R-2000 level of airtightness is the most appropriate one for the operation of the dynamic wall concept. If building paper with higher air permeability were used, the house could be operated with a lower negative pressure, while the appropriate airflow rates were maintained through the dynamic cavities. Non-dynamic air leaks would not constitute as high a percentage of total air infiltration as presently assumed; therefore, a greater percentage of ventilation air would be dynamic.

The following questions need to be answered:

(1) How important is the Glasclad as a flow-straightening component of the envelope?

(2) How important is the current concept of using an air-permeable exterior weather barrier? Could the air intake concept be changed to a more concentrated source, such as holes in an impermeable sheathing?

(3) Can the cavity be engineered to allow volume control over individual cavity air flows to maximize the gains from solar radiation?

(4) How does the ratio of the dynamic wall area to the total envelope area and, more importantly, to the total volume of interior air affect the performance of the dynamic wall house?

(5) Why were the average dynamic air temperatures and, therefore, the average degree of tempering not significantly different (Section 4.4.4) even though average pressure differentials across the second floor walls were lower than across main floor walls?

6.2 PRACTICAL CONSIDERATIONS

For maximum marketability of the dynamic wall house, it will be important to explore ways to reduce the incremental costs of construction. Additionally, for the Alberta marketplace, development of a cost-effective dynamic wall system using stucco rather than siding is required.

Although compressed fibreglass board appears to perform well, it constitutes over half of the incremental cost of the dynamic wall system. The development of less expensive alternative sheathing systems that allow the dynamic wall concept to function acceptably would be a significant forward step. Some possible alternatives are discussed in Appendix G.

Without the monitoring requirement, a closed combustion furnace is not needed. If an induced draft furnace were used instead of the Lennox Pulse, the cost would be reduced by about $800. However, to meet the R-2000 energy budget, elimination of the high efficiency furnace would necessitate the addition of other features to reduce energy consumption.

Further consideration of airtightness from a practical perspective might further reduce the costs associated with airtightness details. For example, air infiltration through the exterior electrical outlets may no longer be a concern. In the wall system proposed for the demonstration house, there may be no need to ensure airtightness at the intersections of the joists and subfloor and plates since the exterior air barrier would cover these areas. Costs associated with this level of airtightness might be further reduced by approximately $200.

6.3 POTENTIAL REDUCTIONS IN INCREMENTAL COSTS

By means of the cost reductions described in the preceding section, the incremental cost of the dynamic wall house could be reduced as follows:

Envelope (2 x 6 framing w/fibreboard and taped Tyvek)	$500.00
Airtightness	400.00
Mechanical systems	
Induced draft furnace in lieu of closed combustion system	600.00
Induced draft hot water tank	350.00
Central exhaust system	445.00

Reduced incremental cost	$2295.00

If the fibreboard could be eliminated, leaving wall systems with only Tyvek between the stud cavities and the exterior finish, this incremental cost of $2295 could be reduced to the $1600 to $1800 range.

It is important to consider the base from which incremental costs are being compared. For example, currently the building code requires only 2 x 4 framed walls; however, the use of 2 x 6 framed walls has been assumed since these are being used now in almost all homes built in Alberta.

Similar changes are gradually occurring in the mechanical systems being installed. The industry is gradually moving away from naturally aspirating gas appliances. Due to the concern for air quality, the industry also seems to be moving towards some form of mechanical ventilation system. The logical conclusion to this movement is some form of system that provides continuous ventilation. If it is assumed that the mechanical systems mentioned here are, or will shortly become, "standard" equipment, then the incremental costs for the dynamic wall house could fall below $1000.

If it is commonly believed that all houses should be built with a reasonably airtight envelope and that it is also important to have a reasonably good exterior weather barrier, then much of the remaining incremental cost should also disappear.

APPENDIX A

BLOWER DOOR AIR TEST REPORTS

howell·mayhew engineering,inc.

15006 • 103 AVENUE
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(403) 484·0478

AIR LEAKAGE TEST REPORT

Apr 4, 1989

Name: RESIDENTIAL CONSTRUCTION GP Address: #94 Carmel Rd. Sherwood Park

Technician: R. Thrall Project Name: Dynamic Wall

Volume = 815 m^3 Envelope = 426 m^2

House pressure:
Initial = 0 Pa
Final = 0 Pa
Backgrnd = 0 Pa

Comments on the wind speed: calm km/h
Barometric pressure = 94.70 kPa
Indoor air temperature = 24 °C
Outdoor air temperature = -4 °C

Reading #	Measured house pressure (Pa)	Corrected house pressure (Pa)	Fan pressure (Pa)	# holes plugged (-1=open)	Corrected Flow (cfm)	Maximum Error (must be < 6%) (%)
1.	50	50.0	223	6	456 (215)	2.1
2.	44	44.0	172	6	404 (191)	1.1
3.	40	40.0	145	6	373 (176)	2.4
4.	33	33.0	112	6	330 (156)	1.0
5.	29	29.0	94	6	304 (143)	.1
6.	24	24.0	75	6	274 (129)	2.6
7.	19	19.0	50	6	226 (107)	.1

Air Leakage Test Results

C = 28.47 r = .996 (must be > 0.990)

n = .704 (between 0.5 and 1.0) RSE$_{10}$ = 3.6% (must be < 7%)

Q_{50} = 447 cfm Air change$_{50}$ = .93 per hour

Q_{10} = 144 cfm Equivalent leakage area = 42 in² at 10 Pa

Comments: (Major leakage sites, recommendations...)

This is a test carried out prior to ventilation holes being drilled at baseboard level.

howell·mayhew engineering, inc.

15006 · 103 AVENUE
EDMONTON · ALBERTA · T5P 0N8
(403) 484·0476

AIR LEAKAGE TEST REPORT

Apr 4, 1989

Name: RESIDENTIAL CONSTRUCTION GP Address: #94 Carmel Rd. Sherwood Park

Technician: R. Thrall Project Name: Dynamic Wall

Volume = 815 m^3 Envelope = 426 m^2

House pressure:
Initial = 0 Pa
Final = 0 Pa
Backgrnd = 0 Pa

Comments on the wind speed: calm km/h
Barometric pressure = 94.70 kPa
Indoor air temperature = 25 °C
Outdoor air temperature = -3 °C

Reading	Measured house pressure	Corrected house pressure	Fan pressure	# holes plugged	Corrected Flow	Maximum Error (must be < 6%)
#	(Pa)	(Pa)	(Pa)	(-1=open)	(cfm)	(%)
1.	58	58.0	175	4	707 (334)	1.7
2.	50	50.0	135	4	628 (296)	.2
3.	45	45.0	112	4	577 (272)	1.6
4.	38	38.0	85	4	509 (240)	2.9
5.	30	30.0	63	4	445 (210)	.6
6.	25	25.0	52	4	407 (192)	2.8
7.	20	20.0	36	4	345 (163)	1.1

Air Leakage Test Results

C = 46.06 r = .997 (must be > 0.990)

n = .668 (between 0.5 and 1.0) RSE_{10} = 3.6% (must be < 7%)

Q_{50} = 629 cfm Air $change_{50}$ = 1.31 per hour

Q_{10} = 215 cfm Equivalent leakage area = 63 in^2 at 10 Pa

Comments: (Major leakage sites, recommendations...)

This is a test carried out after ventilation holes were drilled at baseboard level.

howell·mayhew engineering, inc.

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(403) 484·0478

AIR LEAKAGE TEST REPORT

Feb 5, 1990

Name: Smith Home
Address: 94 Carmel Road

Technician: R. Thrall
Project Name: Dynamic Wall Test

Volume = 815 m^3

House pressure:
Initial = 0 Pa
Final = 0 Pa
Backgrnd = 0 Pa

Comments on the wind speed: calm km/h
Barometric pressure = 92.48 kPa
Indoor air temperature = 20 °C
Outdoor air temperature = -19 °C

Reading #	Measured house pressure (Pa)	Corrected house pressure (Pa)	Fan pressure (Pa)	# holes plugged (-1=open)	Corrected Flow (cfm)	Maximum Error (must be < 6%) (%)
1.	53	53.0	250	4	798	1.7
2.	48	48.0	200	4	721	1.4
3.	41	41.0	158	4	648	.9
4.	31	31.0	100	4	526	1.8
5.	24	24.0	73	4	456	2.1
6.	17	17.0	42	4	355	1.5
7.	13	13.0	26	4	286	1.2

Air Leakage Test Results

C = 46.6
r = .998 (must be > 0.990)

n = .711 (between 0.5 and 1.0)
RSE$_{10}$ = 2.5% (must be < 7%)

Q_{50} = 753 cfm
Air change$_{50}$ = 1.57 per hour

Q_{10} = 240 cfm
Equivalent leakage area = 70 in^2 at 10 Pa

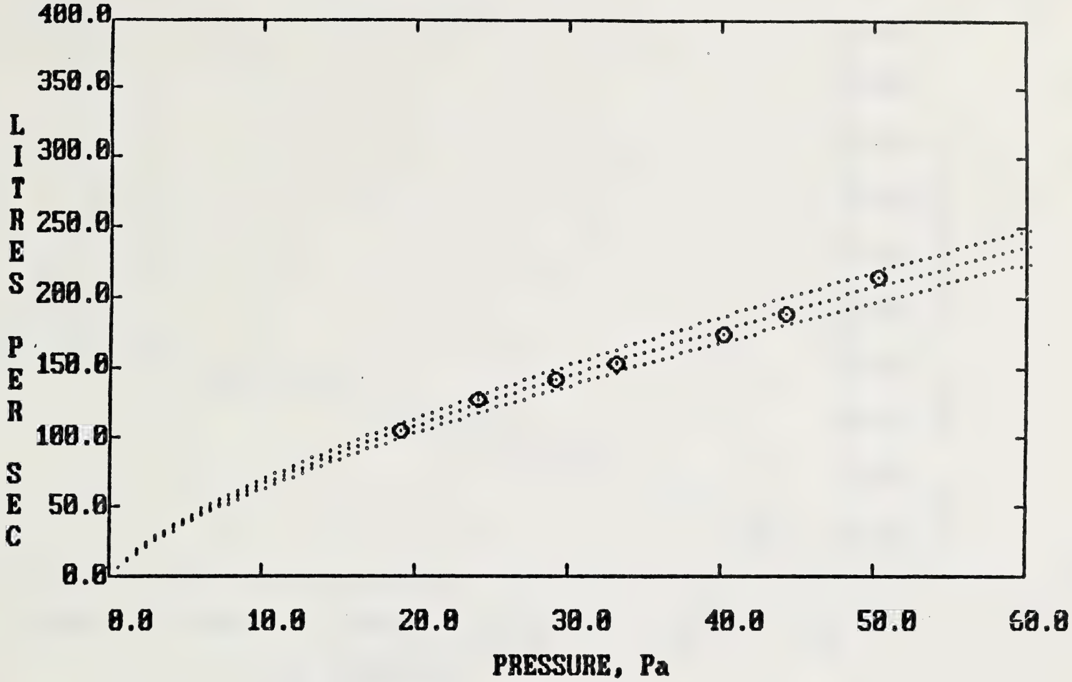
Comments: (Major leakage sites, recommendations...)

This test was carried out while the intake and exhaust hoods were all sealed. The dynamic baseboard area is a source of leakage.

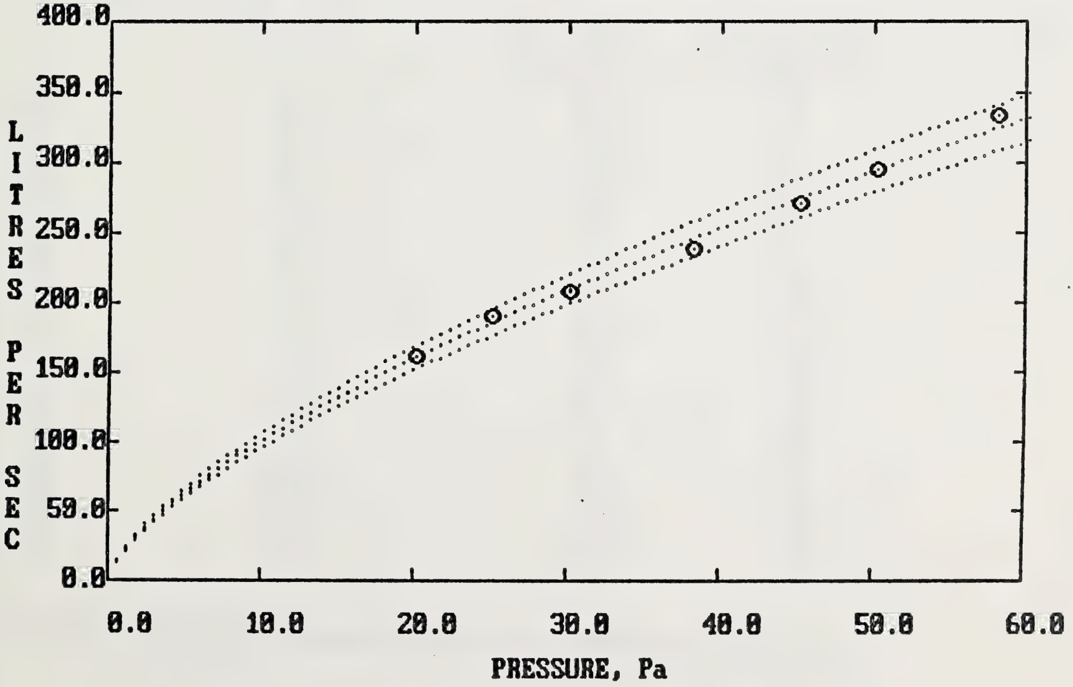
APPENDIX B

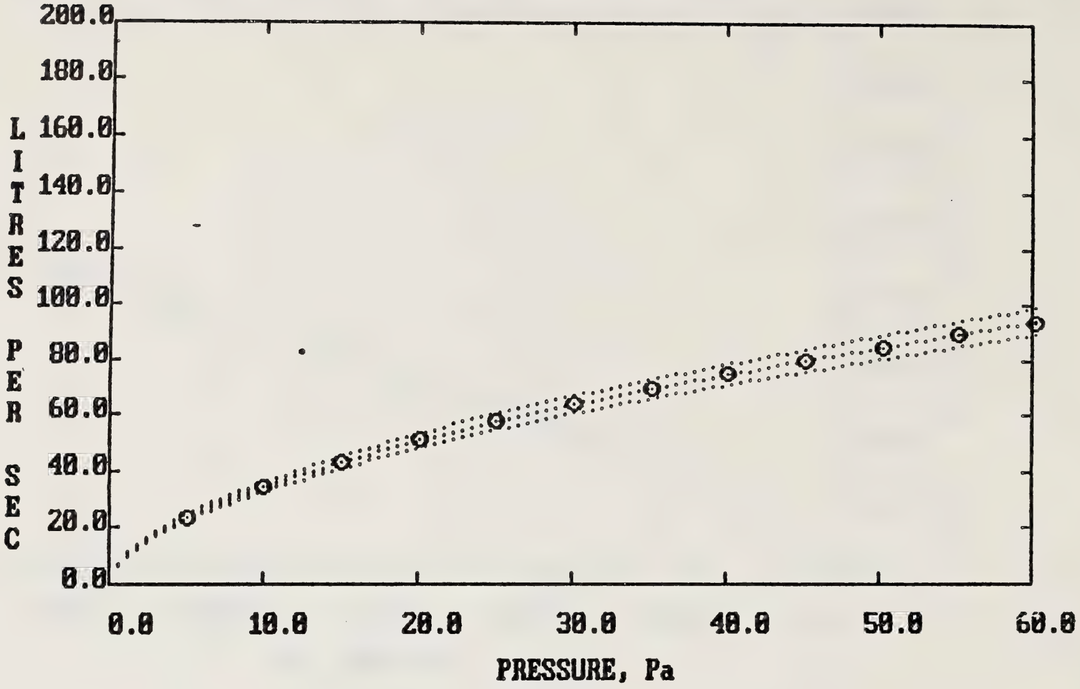
ANALYSIS OF AIR FLOWS BASED ON BLOWER DOOR TESTS

PLOT OF AIR TEST DATA (PRIOR TO DYNAMIC AIR HOLES .93 ACH)



PLOT OF AIR TEST DATA (AFTER DYNAMIC AIR HOLES 1.31 ACH)





Pressure Difference (Pa)	Flow Through Holes (l/s)	Total Flow (l/s)	%Through Holes
2	14	36	38.1
4	20	57	35.9
6	26	74	34.7
8	30	89	33.9
10	34	103	33.2
12	38	116	32.7
14	41	128	32.3
16	45	140	31.9
18	48	151	31.5
20	51	162	31.2
30	64	211	30.1
40	75	255	29.3
50	85	295	28.7
60	94	333	28.2
70	102	368	27.8
80	110	402	27.5
90	118	434	27.2
100	125	466	26.9

PREDICTED DYNAMIC AIR FLOW RATES BASED ON PLOTTED CURVES OF AIR TEST DATA.

APPENDIX C

DAILY AVERAGED ENVELOPE PRESSURE DIFFERENTIALS

DECEMBER: DAILY AVERAGED ENVELOPE PRESSURE DIFFERENTIAL (PA)

				Component Daily Wall Pressure Averages										Combined Daily Wall Pressure Averages						
DEC	WIND SPEED (km/h)	DIR	EXHAUST FLOW (l/s)	CEIL	2-N	2-E	2-S	2-W	1-N	1-E	1-S	1-W	BSMT	2-NS	2-EW	2-TTL	1-NS	1-EW	1-Ttl	TOTAL HOUSE
01	*2*	*SE.S*	*13.0*	*-1.3*	*-3.7*	*-4.4*	*-2.1*	*-3.8*	*-1.0*	*-1.6*	*-1.0*	*-.3*	*5.8*	*-2.9*	*-4.1*	*-3.5*	*-1.0*	*-1.0*	*-1.0*	*-2.2*
02	*1*	*SE.S*	*11.0*	*-1.5*	*-5.0*	*-7.7*	*-2.8*	*-4.0*	*-1.5*	*-4.8*	*-5.7*	*-.7*	*11.4*	*-3.9*	*-5.9*	*-4.9*	*-3.6*	*-2.8*	*-3.2*	*-4.0*
03	*0*	*SW.S*	*13.7*	*-1.1*	*-3.9*	*-4.2*	*-1.9*	*-3.0*	*-1.0*	*-1.8*	*1.1*	*.2*	*6.6*	*-2.9*	*-3.6*	*-3.3*	*.1*	*-.8*	*-.4*	*-1.8*
04	*0*	*SW.W*	*14.0*	*-1.1*	*-3.4*	*-3.8*	*-2.6*	*-3.1*	*-.9*	*-1.4*	*.9*	*.2*	*5.6*	*-3.0*	*-3.5*	*-3.2*	*.0*	*-.6*	*-.3*	*-1.8*
05	*0*	*N.NW*	*13.6*	*-1.3*	*-2.9*	*-3.8*	*-3.9*	*-3.8*	*-.5*	*-.8*	*-.5*	*.1*	*5.0*	*-3.4*	*-3.8*	*-3.6*	*-.5*	*-.4*	*-.4*	*-2.0*
06	*1*	*E.NE*	*35.2*	*-.8*	*-1.8*	*-2.3*	*-1.8*	*-2.1*	*.9*	*1.4*	*2.4*	*1.5*	*6.5*	*-1.6*	*-2.2*	*-2.0*	*1.7*	*1.5*	*1.6*	*-.2*
Exhaust Fan @ 0.32 ACH																				
07	8	S.SW	71.7	.4	2.5	2.4	6.4	6.3	4.1	5.6	10.0	4.9	11.6	4.5	4.4	4.4	7.1	5.3	6.2	5.3
08	8	SE,NW	71.8	.1	3.3	2.2	3.9	2.8	4.0	5.2	7.4	4.5	10.2	.0	2.5	1.3	5.7	4.9	5.3	3.3
09	13	N.NW	71.7	.0	8.1	3.4	2.2	2.4	7.7	7.6	7.8	6.6	13.3	5.2	2.9	4.0	7.8	7.1	7.4	5.7
10	11	NW,SW	71.7	.0	5.4	2.7	3.4	3.5	6.1	7.2	10.0	7.1	15.7	4.4	3.1	3.8	8.1	7.2	7.6	5.7
11	18	NW.SW	71.3	.1	11.0	4.1	5.2	6.4	6.2	5.8	9.4	7.1	15.0	8.1	5.3	6.7	7.8	6.5	7.1	6.9
12	13	NW,W	72.4	.1	10.0	4.8	3.4	5.5	5.7	6.1	6.4	6.3	11.6	6.7	5.2	5.9	6.1	6.2	6.1	6.0
13	6	SW,W	72.6	.1	1.4	1.1	1.9	1.8	3.1	3.8	5.4	4.1	11.0	1.7	1.5	1.6	4.3	4.0	4.1	2.8
14	16	S,SE	70.4	.2	6.3	2.6	10.0	4.6	6.6	5.1	13.0	6.0	17.8	8.2	3.6	5.9	9.8	5.6	7.7	6.8
15	8	N,NE	72.8	.1	2.9	1.9	1.3	1.3	5.2	5.6	5.2	4.6	10.9	2.1	1.6	1.9	5.2	5.1	5.2	3.5
AVG	11		71.8	.1	5.7	2.8	4.2	3.8	5.4	5.8	8.3	5.7	13.0	4.5	3.3	3.9	6.9	5.7	6.3	5.1
STD	4		.7	.1	3.4	1.1	2.7	1.9	1.5	1.1	2.5	1.2	2.6	2.9	1.4	2.0	1.7	1.1	1.3	1.5
16	*8*	*SE.N*	*72.5*	*-.3*	*.7*	*-.2*	*1.0*	*-.1*	*3.3*	*3.9*	*5.6*	*3.7*	*11.5*	*.9*	*-.2*	*.4*	*4.5*	*3.8*	*4.1*	*2.2*
17	*10*	*N.NE*	*37.5*	*-.7*	*-.8*	*-3.6*	*-4.6*	*-4.5*	*2.6*	*1.8*	*1.4*	*1.7*	*7.6*	*7.6*	*-4.1*	*1.8*	*2.0*	*1.8*	*1.9*	*1.8*
Exhaust Fan Off																				
18	5	SW.S	0	-.8	-3.1	-4.1	-2.9	-3.4	1.1	1.7	3.9	2.4	10.5	-3.0	-3.8	-3.4	2.5	2.1	2.3	-.6
19	7	N.NE	0	.0	-4.0	-4.4	-4.7	-4.8	2.0	2.5	2.5	1.9	9.3	-4.4	-4.6	-4.5	2.3	2.2	2.2	-1.1
20	4	N.NW	0	-.9	-3.1	-4.8	-4.6	-4.6	1.6	2.3	3.8	2.5	10.9	-3.9	-4.7	-4.3	2.7	2.4	2.6	-.9
21	13	S.SE	0	-.8	-4.2	-8.1	2.2	-4.1	.9	-1.0	9.5	1.7	16.1	-1.0	-6.1	-3.6	5.2	.4	2.8	-.4
22	15	S,SW	0	-.6	-3.9	-6.3	2.7	-1.9	.5	-1.8	7.6	1.8	13.9	-.6	-4.1	-2.4	4.1	.0	2.0	-.2
23	12	W.SW	0	-.4	-1.3	-2.2	-.5	-.9	.3	-.2	2.4	1.4	7.7	-.9	-1.6	-1.2	1.4	.6	1.0	-.1
24	14	W.NW	0	-.4	2.1	-1.5	-1.0	-.4	.5	-.2	1.4	1.2	6.7	.6	-1.0	-.2	1.0	.5	.7	.3
25	13	SW,NW	0	-.4	-.5	-2.2	.1	-.7	.7	-.4	3.1	1.6	8.4	-.2	-1.5	-.8	1.9	.6	1.3	.2
26	12	W,SW	0	-.4	2.4	-1.3	-1.2	-.1	.6	-.2	.8	1.2	7.5	.6	-.7	-.1	.7	.5	.6	.3
27	8	N,S	0	-.4	-.9	-2.1	-2.6	-2.0	.9	.3	.9	.9	6.0	-1.8	-2.1	-1.9	.9	.6	.8	-.6
28	9	S,N	0	-.5	-1.5	-3.2	-.5	-2.0	1.0	.0	2.8	1.2	8.2	-1.0	-2.6	-1.8	1.9	.6	1.3	-.3
29	13	W.NW	0	-.4	2.3	-1.8	-1.0	-.3	.9	.1	1.8	1.6	7.2	.7	-1.1	-.2	1.4	.9	1.1	.5
30	10	NW,W	0	-.5	1.7	-1.7	-2.0	-.8	.8	.3	.9	1.3	6.2	-.2	-1.3	-.7	.9	.8	.8	.1
31	14	S,SW	0	-.5	-1.9	-4.8	2.5	-1.4	.5	-1.5	5.9	1.3	11.4	.3	-3.1	-1.4	3.2	-.1	1.6	.1
AVG	11		0	-.5	-1.1	-3.5	-1.0	-2.0	.9	.1	3.4	1.6	9.3	-1.1	-2.7	-1.9	2.1	.9	1.5	-.2
STD	4		0	.2	2.4	2.0	2.3	1.6	.5	1.3	2.6	.5	3.0	1.6	1.7	1.5	1.3	.8	.7	.5

LEGEND

CEIL	- ceiling pressure
#-N	- indicates main or second floor and wall direction
BSMT	- basement rim joist pressure
#-NS	- indicates average pressure of opposing walls
#-TTL	- indicates average total wall pressure of main or second floor
TOTAL HOUSE	- indicates average of all main and second floor walls
DIR	- wind direction
STD	- standard deviation

NOTE: Data in italics has not been used in the calculations.

JANUARY: DAILY AVERAGED ENVELOPE PRESSURE DIFFERENTIAL (PA)

				Component Daily Averages										Combined Daily Wall Pressure Averages						
JAN	WIND SPEED (km/h)	DIR	EXHAUST FLOW (l/s)	CEIL	2-N	2-E	2-S	2-W	1-N	1-E	1-S	1-W	BSMT	2-NS	2-EW	2-TTL	1-NS	1-EW	1-TTL	TOTAL HOUSE
01	*10*	*SW.N*	*72.1*	*-.1*	*.7*	*.6*	*1.2*	*.8*	*3.2*	*3.4*	*4.5*	*9.9*	*5.8*	*1.0*	*.7*	*.8*	*3.9*	*6.7*	*5.3*	*3.0*
02	*12*	*S.N*	*63.1*	*.0*	*1.8*	*1.7*	*2.4*	*1.6*	*6.1*	*6.6*	*6.6*	*5.0*	*12.5*	*2.1*	*1.7*	*1.9*	*6.4*	*5.8*	*6.1*	*4.0*
Exhaust Fan @ 0.23 ACH																				
03	10	N.S	54.2	-.1	2.3	1.5	1.4	1.0	5.6	6.3	6.4	4.8	12.5	1.9	1.3	1.6	6.0	5.6	5.8	3.7
04	7	SE,N	54.6	-.1	1.7	1.4	2.5	1.6	4.5	5.8	7.6	5.1	13.6	2.1	1.5	1.8	6.1	5.5	5.8	3.8
05	11	S.SW	53.2	.0	1.9	.3	5.5	2.5	4.1	4.0	9.7	5.1	15.3	3.7	1.4	2.6	6.9	4.6	5.7	4.1
06	11	SW,W	50.9	.1	1.4	1.5	4.7	3.2	3.8	4.1	8.3	5.3	13.8	3.1	2.4	2.7	6.1	4.7	5.4	4.0
07	11	S.SW	51.1	.0	3.2	1.6	4.5	3.1	3.8	4.0	7.6	4.7	12.7	3.9	2.4	3.1	5.7	4.4	5.0	4.1
AVG	10		52.8	-.0	2.1	1.3	3.7	2.3	4.4	4.8	7.9	5.0	13.6	2.9	1.8	2.3	6.1	4.9	5.5	3.9
STD	2		1.7	.1	.7	.5	1.7	1.0	.8	1.1	1.2	.2	1.1	.9	.5	.6	.4	.5	.3	.2
08	*9*	*SW.W*	*59.5*	*-.1*	*.0*	*.3*	*2.3*	*1.4*	*2.5*	*2.9*	*5.7*	*3.7*	*10.7*	*.0*	*.9*	*.4*	*4.1*	*3.3*	*3.7*	*2.1*
Exhaust Fan @ 0.28 ACH																				
09	10	S,SW	63.0	-.2	-.4	-1.5	2.3	.2	1.6	1.3	5.3	2.3	9.2	1.0	-.7	.2	3.5	1.8	2.6	1.4
10	20	NW.W	64.5	-.5	15.2	1.2	-3.0	2.5	3.0	-.3	-.7	2.3	4.3	6.1	1.9	4.0	1.2	1.0	1.1	2.5
11	11	W.SW	63.7	-.5	.0	-2.1	-.7	-1.0	1.2	1.1	3.7	2.1	9.2	-.4	-1.6	-1.0	2.5	1.6	2.0	.5
12	8	S.SW	63.5	-.4	-1.7	-3.2	.5	-1.7	.7	.2	4.2	1.1	7.4	-.6	-2.5	-1.5	2.5	.7	1.6	.0
AVG	12		63.7	-.4	3.3	-1.4	-.2	.0	1.6	.6	3.1	2.0	7.5	1.5	-.7	.4	2.4	1.3	1.8	1.1
STD	5		.6	.1	8.0	1.9	2.2	1.8	1.0	.8	2.6	.6	2.3	3.1	1.9	2.5	.9	.5	.7	1.1
13	*5*	*S.SW*	*69.1*	*-.2*	*.6*	*.3*	*1.2*	*.8*	*2.1*	*3.8*	*4.4*	*2.3*	*5.3*	*.9*	*.6*	*.7*	*3.3*	*3.1*	*3.2*	*1.9*
14	*7*	*SW.W*	*63.8*	*-.3*	*-.8*	*-1.0*	*-.1*	*-.5*	*.9*	*1.2*	*3.0*	*1.4*	*4.1*	*-.5*	*-.8*	*-.6*	*2.0*	*1.3*	*1.6*	*.5*
15	*8*	*S.SW*	*9.8*	*-.6*	*-3.8*	*-4.4*	*-2.8*	*-3.9*	*-1.2*	*-1.9*	*.2*	*-1.1*	*1.7*	*-3.3*	*-4.2*	*-3.7*	*-.5*	*-1.5*	*-1.0*	*-2.4*
16	*9*	*N.SE*	*15.1*	*-.6*	*-3.0*	*-4.2*	*-4.6*	*-4.9*	*.4*	*-.7*	*-1.1*	*-1.1*	*.6*	*-3.8*	*-4.6*	*-4.2*	*-.4*	*-.9*	*-.6*	*-2.4*
17	*9*	*SW.W*	*29.6*	*-.8*	*-5.1*	*-5.9*	*-4.1*	*-4.9*	*-1.8*	*-2.5*	*.5*	*-1.0*	*2.8*	*7.6*	*-5.4*	*1.1*	*-.7*	*-1.8*	*-1.2*	*-.1*
18	*12*	*SW.W*	*73.2*	*-.3*	*2.1*	*-.3*	*.5*	*.9*	*1.8*	*1.8*	*4.1*	*2.6*	*6.7*	*1.3*	*.3*	*.8*	*3.0*	*2.2*	*2.6*	*1.7*
Exhaust Fan @ 0.32 ACH																				
19	9	SW.S	72.6	.1	2.4	2.1	5.2	3.7	4.4	5.1	9.1	5.0	11.1	3.8	2.9	3.4	6.8	5.1	5.9	4.6
20	13	SW.W	71.9	.4	4.5	4.3	6.4	5.8	5.4	6.4	10.3	2.5	10.9	5.5	5.1	5.3	7.9	4.5	6.2	5.7
21	12	W.NW	67.3	.3	8.1	5.2	5.2	5.9	5.3	6.6	7.8	5.8	9.4	6.7	5.6	6.1	6.6	6.2	6.4	6.2
22	9	S,SW	72.1	.2	2.8	3.0	5.1	3.7	4.2	5.4	8.3	4.9	10.0	4.0	3.4	3.7	6.3	5.2	5.7	4.7
23	11	NW,W	72.6	.0	7.0	3.8	3.1	4.3	4.8	5.4	6.3	4.9	8.0	5.1	4.1	4.6	5.6	5.2	5.4	5.0
24	10	SW,W	72.2	.0	3.2	2.8	4.6	3.9	4.5	5.6	8.8	5.4	10.9	3.9	3.4	3.6	6.7	5.5	6.1	4.9
25	11	S,SW	71.1	.1	3.3	2.7	6.9	4.3	4.9	5.3	10.2	5.3	11.9	5.1	3.5	4.3	7.6	5.3	6.4	5.4
26	14	N,NW	72.1	-.3	8.9	2.9	1.5	1.6	7.8	6.3	6.9	5.5	9.1	5.2	2.3	3.7	7.4	5.9	6.6	5.2
27	7	S,SE	71.3	-.3	1.8	1.6	4.2	2.3	4.4	5.8	9.4	4.7	11.4	3.0	2.0	2.5	6.9	5.3	6.1	4.3
28	11	N,NE	72.0	-.1	1.5	3.1	1.1	.9	7.8	9.2	6.2	4.6	8.5	1.3	2.0	1.7	7.0	6.9	7.0	4.3
AVG	11		71.5	.0	4.4	3.2	4.3	3.6	5.4	6.1	8.3	4.9	10.1	4.3	3.4	3.9	6.8	5.5	6.2	5.0
STD	2		1.6	.2	2.7	1.0	1.9	1.6	1.3	1.2	1.5	.9	1.3	1.5	1.2	1.3	.7	.7	.5	.6
29	8	N.NE	71.6	-.6	.8	-.3	-1.4	-1.5	5.3	6.4	6.2	3.6	9.2	-.3	-.9	-.6	5.8	5.0	5.4	2.4
30	7	N.NE	70.8	-.8	-2.6	-3.4	-4.3	-4.2	2.6	3.4	3.6	1.7	6.7	-3.5	-3.8	-3.6	3.1	2.6	2.8	-.4
31	6	S.W	71.0	-.5	.1	-.3	.9	.0	4.3	6.1	9.3	4.9	12.6	.5	-.2	.2	6.8	5.5	6.2	3.2

LEGEND

Ceil	- ceiling pressure
#-N	- indicates main or second floor and wall direction
Bmt	- basement rim joist pressure
#-NS	- indicates average pressure of opposing walls
#-Ttl	- indicates average total wall pressure of main or second floor
House Total	- indicates average of all main and second floor walls
Dir	- wind direction
STD	- standard deviation

NOTE: Data in italics has not been used in calculations.

FEBRUARY: DAILY AVERAGED ENVELOPE PRESSURE DIFFERENTIAL (PA)

				Component Daily Averages										Combined Daily Wall Pressure Averages						
FEB	WIND SPEED (km/h)	DIR	EXHAUST FLOW (l/s)	CEIL	2-N	2-E	2-S	2-W	1-N	1-E	1-S	1-W	BSMT	2-NS	2-EW	2-TTL	1-NS	1-EW	1-TTL	TOTAL HOUSE
01	*11*	*SE.E*	*70.1*	*-.6*	*-3.9*	*-3.6*	*1.1*	*-3.6*	*1.0*	*1.3*	*7.8*	*1.3*	*10.4*	*-1.4*	*-3.6*	*-2.5*	*4.4*	*1.3*	*2.9*	*.2*
02	*7*	*S.SE*	*70.3*	*-.3*	*-.8*	*-1.6*	*1.0*	*-1.0*	*2.3*	*2.6*	*6.3*	*2.2*	*8.5*	*.1*	*-1.3*	*-.6*	*4.3*	*2.4*	*3.4*	*1.4*
Exhaust Fan Off																				
03	12	S,SW	.0	-.6	-3.6	6.8	-.7	-3.4	-.9	-3.7	3.5	-.8	5.7	-2.2	1.7	-.2	1.3	-2.3	-.5	-.4
04	9	SW,W	.0	-.6	-4.0	-4.5	-2.7	-3.6	-1.0	-1.5	1.3	-.6	3.2	-3.4	-4.1	-3.7	.2	-1.1	-.5	-2.1
05	10	SW,S	.0	-.6	-3.9	-5.1	-1.6	-3.4	-1.0	-2.2	2.3	-.5	4.3	-2.8	-4.3	-3.5	.7	-1.4	-.4	-1.9
06	6	SW,W	.0	-.6	-3.8	-4.3	-2.9	-3.5	.0	-1.3	1.0	-.5	2.9	-3.4	-3.9	-3.6	.5	-.9	-.2	-1.9
07	4	S,SW	.0	-.6	-3.5	-4.9	-2.0	-3.5	-.9	-1.8	1.8	-.5	3.7	-2.8	-2.8	.5	-2.7	.5	-1.1	-.3
08	10	NW,N	.0	-.7	.5	-4.4	-5.8	-4.3	-.1	-1.2	-1.1	-.7	1.0	-2.7	-4.4	-3.5	-.6	-1.0	-.8	-2.1
09	10	S,SE	.0	-.6	-4.8	-5.9	-.9	-4.8	-1.2	-1.9	3.9	-1.1	5.6	-2.9	-5.4	-4.1	1.4	-1.5	-.1	-2.1
10	8	SW,W	.0	-.4	-1.3	-2.4	-1.4	-1.5	.3	.2	2.2	.5	4.0	-1.4	-2.0	-1.7	1.3	.4	.8	-.4
11	12	N,SE	.0	-.5	1.9	-3.1	-1.7	-3.1	2.5	.2	2.8	-.2	4.2	.1	-3.1	-1.5	2.7	.0	1.3	-.1
12	13	N,NW	.0	-.8	1.5	-4.8	-6.4	-5.8	2.4	.1	.4	-.2	3.4	-2.5	-5.3	-3.9	1.4	-.1	.7	-1.6
13	9	W,SW	.0	-.8	-3.9	-6.1	-2.9	-4.1	.3	-.2	4.9	1.2	9.3	-3.4	-5.1	-4.3	2.6	.5	1.5	-1.4
14	9	SW.W	.0	-.6	-5.0	-4.8	-2.9	-3.7	.5	.8	4.0	1.1	6.8	-4.0	-4.3	-4.1	2.3	1.0	1.6	-1.3
AVG	9		.0	-.6	-2.5	-3.6	-2.7	-3.7	.1	-1.0	2.2	-.2	4.5	-2.6	-3.6	-2.8	.9	-.5	.2	-1.3
STD	3		.0	.1	2.5	3.4	1.8	1.0	1.3	1.3	1.7	.7	2.1	1.1	1.9	1.6	1.5	1.0	.9	.8
15	*9*	*E.NE*	*72.5*	*-.4*	*-3.4*	*-1.0*	*-2.8*	*-2.0*	*3.0*	*6.0*	*4.5*	*2.9*	*7.3*	*-3.1*	*-1.5*	*-2.3*	*3.8*	*4.5*	*4.1*	*.9*
16	*10*	*E.NE*	*72.2*	*-.3*	*-.8*	*1.0*	*-.5*	*-.4*	*4.4*	*7.6*	*6.7*	*4.2*	*9.3*	*-.7*	*.3*	*-.2*	*5.6*	*5.9*	*5.7*	*2.8*
17	*4*	*SW.S*	*71.8*	*-.5*	*-.7*	*-1.3*	*.9*	*-.1*	*3.5*	*4.5*	*8.5*	*4.2*	*11.3*	*.1*	*-.7*	*-.3*	*6.0*	*4.4*	*5.2*	*2.4*
Exhaust Fan @ 0.32 ACH																				
18	7	SW,S	72.2	.0	1.7	.8	3.4	2.4	3.9	4.5	8.6	4.5	10.7	2.6	1.6	2.1	6.3	4.5	5.4	3.7
19	7	SW,S	72.2	.1	1.5	.8	5.2	3.0	3.7	3.5	9.2	4.2	11.0	3.4	1.9	2.6	6.5	3.9	5.2	3.9
20	11	SW,NW	71.9	.1	4.6	2.7	4.0	3.7	4.6	4.7	7.4	4.6	9.0	4.3	3.2	3.8	6.0	4.7	5.3	4.5
21	9	SW.NW	72.3	.0	4.1	1.8	3.2	2.6	4.4	4.1	7.0	4.3	8.8	3.7	2.2	2.9	5.7	4.2	5.0	3.9
22	10	S.SW	72.6	.2	4.3	3.1	3.6	3.9	4.0	4.6	6.1	4.1	7.6	3.8	4.3	4.0	6.9	5.9	6.4	5.2
23	10	NE,N	73.3	.1	3.5	2.8	1.1	1.8	5.6	6.2	4.9	3.9	6.5	2.3	2.3	2.3	5.3	5.1	5.2	3.7
24	16	S,SE	71.1	.0	.2	-1.3	9.4	1.9	3.2	2.3	13.2	3.2	14.8	4.8	.3	2.6	8.2	2.8	5.5	4.0
25	16	NW,W	72.9	-.1	12.0	4.5	2.9	5.4	5.5	4.3	5.6	5.1	7.2	7.5	5.0	6.2	5.6	4.7	5.1	5.7
26	10	S,SW	72.9	.0	2.8	1.4	3.1	2.1	4.7	4.6	7.1	4.1	8.9	3.0	3.0	5.9	3.4	5.9	4.6	5.3
27	7	SW,S	72.5	.1	1.4	1.7	5.9	3.9	4.2	4.4	10.2	5.1	12.3	3.7	2.8	3.2	7.2	4.8	6.0	4.6
28	9	SW,W	72.0	.2	2.0	3.0	7.5	5.3	4.9	5.0	11.0	5.8	13.0	4.8	4.2	4.5	7.9	5.4	6.7	5.6
AVG	10		72.4	.1	3.5	1.9	4.5	3.3	4.4	4.4	8.2	4.4	10.0	4.0	2.8	3.6	6.2	4.7	5.5	4.6
STD	3		.6	.1	3.2	1.5	2.4	1.3	.7	1.0	2.5	.7	2.6	1.4	1.3	1.4	1.3	.9	.6	.8

LEGEND

CEIL	- ceiling pressure
#-N	- indicates main or second floor and wall direction
BSMT	- basement rim joist pressure
#-NS	- indicates average pressure of opposing walls
#-TTL	- indicates average total wall pressure of main or second floor
TOTAL HOUSE	- indicates average of all main and second floor walls
DIR	- wind direction
STD	- standard deviation

NOTE: Data in italics has not been used in calculations.

MARCH: DAILY AVERAGED ENVELOPE PRESSURE DIFFERENTIAL (PA)

				Component Daily Averages									Combined Daily Wall Pressure Averages							
MAR	WIND SPEED (km/h)	DIR	EXHAUST FLOW (l/s)	CEIL	2-N	2-E	2-S	2-W	1-N	1-E	1-S	1-W	BSMT	2-NS	2-EW	2-TTL	1-NS	1-EW	1-TTL	TOTAL HOUSE
01		W.NW	72.0	.3	5.2	4.8	5.6	5.2	5.5	6.5	8.3	5.5	9.9	5.4	5.0	5.2	6.9	6.0	6.5	5.8
02		S,SW	71.9	.2	3.5	3.1	6.5	4.6	4.7	5.3	9.3	5.0	10.7	5.0	3.9	4.4	7.0	5.2	6.1	5.3
03		S.SW	72.6	.0	1.6	1.7	2.6	2.0	3.1	3.8	5.1	3.1	6.6	1.9	2.9	2.4	3.5	5.9	4.7	3.5
04		S,N	72.2	.0	2.4	2.3	3.3	2.7	3.8	4.9	6.2	3.9	7.7	2.5	3.6	3.0	4.4	7.0	5.7	4.4
05		S,SE	71.2	.0	3.0	2.9	5.6	3.6	4.6	5.7	9.2	5.0	10.8	4.3	3.3	3.8	6.9	5.4	6.1	5.0
06		S,SW	71.5	.1	3.5	3.2	5.6	4.0	4.7	5.6	8.5	5.0	9.9	4.6	3.6	4.1	6.6	5.3	6.0	5.0
07		SE,S	70.8	.2	3.9	3.9	7.1	4.8	5.2	6.3	9.9	5.5	11.3	5.5	5.5	8.4	5.6	7.6	6.6	7.5
08	5	NW,W	71.0	.1	10.5	5.1	4.6	6.1	6.1	6.2	7.6	5.9	9.3	7.6	5.6	6.6	6.9	6.1	6.5	6.5
09	10	NW,S	70.4	.2	7.5	4.7	7.8	5.8	5.7	6.1	10.6	5.7	12.0	7.7	5.3	6.5	8.2	5.9	7.0	6.7
10	7	S,N	70.2	.2	3.5	3.6	6.9	4.2	4.8	5.8	9.2	4.7	10.9	5.2	3.9	4.6	7.0	5.3	6.1	5.3
11	13	N,NW	71.6	.2	11.0	4.4	2.1	2.0	9.4	6.7	5.9	4.7	7.5	6.6	3.2	4.9	7.7	5.7	6.7	5.8
12	10	N,NW	71.3	.0	7.1	3.9	3.3	3.2	6.6	6.3	7.2	4.9	8.9	5.2	3.6	4.4	6.9	5.6	6.3	5.3
13	7	SW,S	70.8	.1	2.6	2.5	5.7	4.1	4.7	5.4	9.6	5.2	11.6	4.2	3.3	3.7	7.2	5.3	6.2	5.0
14	8	S,SW	70.8	.1	3.8	3.2	5.0	3.9	5.0	5.7	8.4	5.1	10.0	4.4	3.6	4.0	6.7	5.4	6.1	5.0
15	13	NW,W	71.5	.2	9.9	5.5	4.3	5.8	6.3	6.3	6.9	5.9	8.4	7.1	5.7	6.4	6.6	6.1	6.4	6.4
16	11	W.NW	71.6	.1	7.4	4.6	4.0	4.8	5.5	5.9	6.9	5.2	8.5	5.7	4.7	5.2	6.2	5.6	5.9	5.5
17	10	NW,N	72.2	.0	4.7	2.3	1.9	2.2	4.2	4.3	4.7	3.5	6.3	3.3	2.3	2.8	4.5	3.9	4.2	3.5
18	13	S,SW	71.0	.2	2.3	.6	7.6	4.1	4.1	3.2	10.6	4.7	12.8	5.0	2.4	3.7	7.4	4.0	5.7	4.7
19	7	W,SW	71.2	.1	4.2	4.1	4.6	4.4	4.6	5.7	6.9	4.9	9.1	4.4	4.3	4.3	5.8	5.3	5.5	4.9
20	12	N,NE	71.4	.2	3.7	4.3	2.7	2.4	7.5	8.7	6.3	5.0	8.3	3.2	3.4	3.3	6.9	6.9	6.9	5.1
21	16	N,NW	71.7	.0	13.6	4.4	1.3	3.0	9.0	5.6	6.4	6.3	8.4	7.5	3.7	5.6	7.7	6.0	6.8	6.2
22	14	NW,N	71.8	.0	10.6	4.1	2.1	3.3	7.4	6.6	6.9	5.8	9.1	4.8	5.0	4.9	8.0	7.5	7.7	6.3
23	7	SW,W	71.4	.1	1.8	2.4	4.3	3.3	4.6	6.0	9.4	5.3	11.6	3.1	2.9	3.0	7.0	5.7	6.3	4.6
24	13	SW,N	71.4	.1	5.2	3.7	4.6	4.1	5.5	5.8	8.4	5.6	10.4	4.9	3.9	4.4	7.0	5.7	6.3	5.4
25		S,SE	71.4	.1	2.4	2.3	5.4	3.0	3.8	4.5	8.3	3.9	9.8	3.9	2.7	3.3	6.1	4.2	5.1	4.2
26		S,NW	71.2	.3	5.2	4.0	5.3	4.4	5.0	5.7	7.7	4.9	9.2	5.3	5.3	7.2	5.1	6.4	5.7	6.5
27		W,NW	71.8	.0	3.9	3.3	3.5	3.5	4.0	4.8	5.5	4.1	7.7	3.7	3.4	3.6	4.8	4.5	4.6	4.1
28	7	SW,W	70.8	.4	3.7	3.9	6.9	5.4	5.0	5.7	9.6	5.7	11.1	5.3	4.7	5.0	7.3	5.7	6.5	5.7
29	12	SW,W	70.5	.3	3.5	4.4	7.1	5.9	5.0	6.0	9.9	6.1	11.4	5.3	5.2	5.2	7.5	6.1	6.8	6.0
AVG	10		71.4	.1	5.2	3.6	4.7	4.0	5.4	5.7	7.9	5.0	9.6	4.9	4.0	4.6	6.5	5.7	6.1	5.3
STD	3		.6	.1	3.2	1.1	1.8	1.2	1.5	1.0	1.7	.8	1.7	1.4	1.0	1.4	1.2	.9	.8	1.0

LEGEND

CEIL	- ceiling pressure
2-N	- indicates main or second floor and wall direction
BSMT	- basement rim joist pressure
2-NS	- indicates average pressure of opposing walls
2-TTL	- indicates average total wall pressure of main or second floor
TOTAL HOUSE	- indicates average of all main and second floor walls
DIR	- wind direction
STD	- standard deviation

NOTE: Data in italics has not been used in calculations.

APPENDIX D

DAILY AVERAGED DYNAMIC AIR TEMPERATURES

DECEMBER: DAILY AVERAGED DYNAMIC AIR TEMPERATURES (°C)

DEC	SOLAR (KJ/m²)	OUT DOOR	SE BED ROOM	2-S DYNA	2-E DYNA	NW BED ROOM	NW BED FLOOR	2-N DYNA	2-W DYNA	FAM ROOM	1-S DYNA	LVG ROOM	LVG RM FLOOR	1-N DYNA	1-E DYNA	1-W DYNA	BSMT	Avg Indoor	2-Avg Dyna	1-Avg Dyna	Avg Dyna	% Temper
01	*799*	*14.3*	*24.1*	*22.4*	*22.3*	*22.8*	*22.8*	*21.6*	*21.0*	*25.2*	*20.7*	*23.6*	*23.4*	*20.6*	*18.6*	*20.8*	*22.3*	*23.9*	*21.8*	*20.2*	*21.0*	
02	*2521*	*15.9*	*23.5*	*18.9*	*23.7*	*22.6*	*22.8*	*22.2*	*21.3*	*23.7*	*17.4*	*23.7*	*23.2*	*21.1*	*18.5*	*20.6*	*22.4*	*23.4*	*21.5*	*19.4*	*20.5*	
03	*3133*	*16.5*	*23.6*	*21.1*	*22.8*	*22.3*	*22.7*	*21.8*	*21.0*	*23.8*	*19.4*	*23.4*	*22.8*	*20.8*	*18.6*	*20.6*	*21.7*	*23.3*	*21.7*	*19.9*	*20.8*	
04	*3338*	*16.2*	*23.5*	*21.8*	*22.6*	*22.2*	*22.6*	*21.7*	*21.1*	*23.9*	*20.3*	*23.2*	*22.7*	*20.7*	*18.7*	*20.6*	*21.5*	*23.2*	*21.8*	*20.1*	*20.9*	
05	*1404*	*15.6*	*23.2*	*21.3*	*22.7*	*22.1*	*22.5*	*22.1*	*21.2*	*23.3*	*19.8*	*23.2*	*22.6*	*20.3*	*18.2*	*20.3*	*21.7*	*23.0*	*21.8*	*19.7*	*20.7*	
06	*1324*	*7.4*	*22.3*	*18.7*	*21.0*	*21.4*	*21.6*	*19.9*	*16.7*	*22.5*	*15.9*	*22.4*	*21.9*	*18.4*	*16.3*	*18.7*	*21.1*	*22.2*	*19.1*	*17.3*	*18.2*	
Exhaust Fan @ 0.32 ACH																						
07	1936	-4.9	21.4	13.5	16.7	20.6	20.4	15.0	5.7	21.2	10.1	21.4	21.1	16.0	13.4	16.5	19.7	21.2	15.1	14.0	14.5	75%
08	1843	-5.4	21.5	13.6	17.1	20.6	20.2	14.6	5.7	21.2	10.9	21.6	21.2	16.3	14.0	16.6	19.9	21.2	15.1	14.5	14.8	76%
09	2451	-15.0	22.2	11.6	15.1	21.0	19.8	11.0	-.2	21.6	7.8	21.9	21.4	13.6	12.1	15.6	20.4	21.7	12.6	12.3	12.4	75%
10	3857	-19.1	21.8	8.7	12.8	20.2	18.7	8.7	-4.8	21.8	5.1	21.3	20.8	11.7	8.8	14.0	19.8	21.3	10.1	9.9	10.0	72%
11	1763	-5.4	22.4	10.6	17.4	21.0	20.0	12.1	2.5	21.6	8.6	22.2	21.3	15.3	12.9	15.7	20.2	21.8	13.4	13.1	13.2	69%
12	3049	-1.5	21.8	15.5	16.9	20.5	19.6	13.2	6.1	21.9	12.9	21.9	21.1	16.3	15.2	16.9	19.3	19.7	15.2	15.3	15.3	79%
13	1769	-.6	22.2	15.4	18.7	21.3	20.7	15.7	8.3	21.4	12.7	22.3	21.4	17.4	16.3	17.6	20.1	21.8	16.6	16.0	16.3	75%
14	778	-2.5	21.9	12.4	17.9	20.9	20.4	14.6	6.8	21.4	10.5	22.2	21.2	16.6	14.9	17.3	20.0	21.6	15.0	14.8	14.9	72%
15	1131	-5.3	22.2	14.6	17.6	21.3	20.4	14.0	6.7	21.5	11.8	22.3	21.3	16.1	15.1	17.0	20.3	21.8	15.4	15.0	15.2	76%
AVG	2064	-6.6	21.9	12.9	16.7	20.8	20.0	13.2	4.1	21.5	10.0	21.9	21.2	15.5	13.6	16.4	20.0	21.3	14.3	13.9	14.1	74%
STD	942	6.3	.3	2.3	1.8	.4	.6	2.2	4.2	.2	2.5	.4	.2	1.8	2.2	1.1	.3	.7	2.0	1.9	1.9	3%
16	*1868*	*-9.9*	*22.4*	*13.8*	*18.0*	*21.3*	*20.7*	*15.3*	*7.8*	*21.4*	*10.1*	*22.3*	*21.3*	*15.8*	*14.4*	*16.8*	*20.3*	*21.9*	*13.7*	*14.3*	*14.0*	
17	*4089*	*-18.4*	*21.9*	*18.0*	*19.6*	*20.7*	*19.9*	*14.4*	*14.6*	*22.0*	*13.0*	*21.6*	*20.7*	*13.2*	*13.1*	*15.6*	*19.7*	*21.6*	*16.7*	*13.7*	*15.2*	
Exhaust Fan Off																						
18	4660	-21.7	22.1	16.0	19.2	20.8	20.1	16.5	13.6	21.9	7.8	21.7	20.7	12.3	11.7	14.8	19.7	21.6	16.3	11.7	14.0	
19	1774	-25.3	22.5	16.6	19.8	21.3	20.6	16.1	14.4	21.6	8.1	22.2	21.0	12.0	10.6	14.9	20.0	21.9	16.6	11.4	14.0	
20	3894	-30.9	22.3	13.6	19.3	20.8	19.9	15.3	13.3	21.9	5.3	21.7	20.4	9.9	9.2	13.6	19.3	21.7	15.4	9.5	12.4	
21	4038	-27.1	22.0	8.6	20.5	20.7	19.8	16.1	13.6	21.7	1.6	21.6	20.3	10.8	9.9	13.8	19.0	21.5	14.7	9.0	11.9	
22	2257	-8.1	22.1	10.2	21.6	21.1	20.6	17.3	14.3	21.5	7.7	22.2	21.1	15.5	13.9	16.0	19.5	21.7	15.9	13.3	14.6	
23	2321	4.9	21.6	18.6	21.2	20.7	20.7	18.6	16.6	21.6	15.9	21.6	21.0	18.0	17.0	18.2	19.0	21.4	18.8	17.3	18.0	
24	1916	5.7	21.4	19.2	21.4	10.6	20.6	18.5	16.4	21.4	16.6	21.6	20.9	18.1	17.3	18.5	19.1	18.8	18.9	17.6	18.3	
25	957	4.5	21.5	18.7	21.5	20.7	20.8	18.7	16.8	21.4	16.0	21.6	21.0	18.2	17.4	18.5	19.3	21.3	18.9	17.5	18.2	
26	3001	5.6	21.5	20.0	21.0	20.6	20.6	18.3	16.4	22.0	17.8	21.4	20.9	18.1	17.4	18.5	19.0	21.4	18.9	18.0	18.4	
27	1255	2.5	21.3	19.4	21.3	20.6	20.6	18.4	17.5	21.3	16.8	21.6	21.0	17.9	17.2	18.4	19.4	21.2	19.2	17.6	18.4	
28	1032	-1.7	21.5	18.3	21.3	20.7	20.6	18.1	17.0	21.4	15.2	21.8	21.1	17.3	16.8	18.0	19.8	21.4	18.7	16.8	17.8	
29	4297	.5	21.6	18.5	20.7	20.5	20.3	17.4	14.9	22.2	16.0	21.5	20.9	17.7	16.4	17.7	19.4	21.5	17.9	17.0	17.4	
30	3253	-.6	21.4	19.5	20.6	20.4	20.1	17.0	14.8	21.9	16.9	21.6	20.9	17.1	16.2	17.6	19.5	21.3	18.0	17.0	17.5	
31	1036	-.8	21.5	15.8	21.7	20.7	20.5	18.4	16.4	21.3	12.9	21.9	21.1	17.4	16.2	17.8	19.8	21.4	18.1	16.1	17.1	
AVG	2549	-6.6	21.7	16.6	20.8	20.0	20.4	17.5	15.4	21.7	12.5	21.7	20.9	15.7	14.8	16.9	19.4	21.3	17.6	15.0	16.3	
STD	1306	13.5	.4	3.6	.8	2.7	.3	1.1	1.4	.3	5.3	.2	.2	3.1	3.1	1.8	.3	.8	1.5	3.3	2.4	

LEGEND

SE BED	- southeast bedroom (master), second floor
#-S	- indicates main or second floor and direction wall is facing
NW BED	- northwest bedroom, second floor
FAM RM	- family room, main floor, south side
LVG RM	- living room, main floor, northeast
#-Avg Dyna	- average temperature of dynamic air on main or second floor
Avg Dyna	- average of main and second floor
Avg Indoor	- average indoor temperature
% Temper	- the portion of the total indoor/outdoor temperature difference that the incoming dynamic air was warmed up to.
STD	- standard deviation

NOTE: Data in italics has not been used in the calculations.

JANUARY: DAILY AVERAGED DYNAMIC AIR TEMPERATURES (°C)

JAN	SOLAR (KJ/m2)	OUT DOOR	SE BED ROOM	2-S DYNA	2-E DYNA	NW BED ROOM	NW BED FLOOR	2-N DYNA	2-W DYNA	FAM ROOM	1-S DYNA	LVG ROOM	LVG RM FLOOR	1-N DYNA	1-E DYNA	1-W DYNA	BSMT	Avg Indoor	2-Avg Dyna	1-Avg Dyna	Avg Dyna	% Temper
01	*9174*	*-.3*	*21.9*	*17.5*	*19.2*	*20.7*	*20.5*	*16.9*	*12.6*	*21.9*	*14.6*	*21.8*	*21.2*	*17.1*	*16.1*	*17.8*	*19.7*	*21.3*	*16.6*	*16.4*	*16.5*	*78%*
02	*13881*	*-8.5*	*21.9*	*14.1*	*16.7*	*20.4*	*19.8*	*13.4*	*6.2*	*21.6*	*10.9*	*21.9*	*21.1*	*14.9*	*13.0*	*16.6*	*20.0*	*21.1*	*12.6*	*13.9*	*13.2*	*73%*
Exhaust Fan @ 0.23 ACH																						
03	12600	-13.2	21.9	12.6	16.2	20.4	19.6	12.4	3.4	21.5	9.0	21.9	21.2	14.1	12.3	15.9	20.0	21.1	13.7	12.8	13.3	77%
04	10968	-13.7	21.9	10.7	15.7	20.5	19.7	12.8	1.6	21.4	7.6	22.0	21.2	14.2	12.2	15.7	20.1	21.1	13.1	12.4	12.7	76%
05	12700	-7.4	22.0	10.8	17.8	20.7	20.1	13.8	3.9	21.5	8.5	22.0	21.2	15.3	13.7	16.2	20.1	21.3	14.1	13.4	13.8	74%
06	13927	1.3	22.1	14.8	18.6	20.9	20.6	16.3	8.9	21.8	12.6	21.9	21.4	17.3	16.4	17.8	19.8	21.5	16.6	16.0	16.3	74%
07	11239	.2	22.0	14.7	18.6	20.9	20.6	16.3	9.1	21.7	12.7	21.9	21.5	17.3	16.3	18.0	20.0	21.4	16.5	16.1	16.3	76%
AVG	**12287**	**-6.6**	**22.0**	**12.7**	**17.4**	**20.7**	**20.1**	**14.3**	**5.4**	**21.6**	**10.1**	**21.9**	**21.3**	**15.6**	**14.2**	**16.7**	**20.0**	**21.3**	**14.8**	**14.2**	**14.5**	**75%**
STD	**1204**	**7.1**	**.1**	**2.0**	**1.4**	**.2**	**.5**	**1.9**	**3.4**	**.2**	**2.4**	**.1**	**.1**	**1.6**	**2.1**	**1.1**	**.1**	**.2**	**1.6**	**1.8**	**1.7**	**1%**
08	*11294*	*1.9*	*22.2*	*17.1*	*18.5*	*21.0*	*20.7*	*17.0*	*10.8*	*22.5*	*14.9*	*21.5*	*21.3*	*17.3*	*16.6*	*18.0*	*19.6*	*21.5*	*15.9*	*16.7*	*16.3*	*73%*
Exhaust Fan @ 0.28 ACH																						
09	8840	.3	21.8	15.8	19.9	21.1	20.9	17.3	12.8	21.6	13.2	21.1	21.3	17.3	16.5	17.5	17.8	21.3	16.5	16.1	16.3	76%
10	5312	-1.7	21.9	19.1	20.7	20.7	20.1	14.3	10.2	21.9	17.2	21.0	21.2	16.9	16.5	17.4	19.5	21.1	16.1	17.0	16.5	80%
11	19732	-5.9	22.5	18.3	20.7	21.4	20.8	17.0	13.0	22.9	14.2	21.7	21.7	16.6	15.9	17.3	19.9	21.8	17.3	16.0	16.6	81%
12	17777	-6.7	22.5	16.8	19.5	21.9	21.7	17.6	14.9	20.1	10.7	18.8	16.9	13.6	11.1	12.5	17.9	20.3	17.2	12.0	14.6	79%
AVG	**12915**	**-3.5**	**22.2**	**17.5**	**20.2**	**21.3**	**20.9**	**16.6**	**12.7**	**21.6**	**13.8**	**20.7**	**20.3**	**16.1**	**15.0**	**16.2**	**18.8**	**21.1**	**16.7**	**15.3**	**16.0**	**79%**
STD	**6941**	**3.4**	**.4**	**1.5**	**.6**	**.5**	**.7**	**1.5**	**1.9**	**1.2**	**2.7**	**1.3**	**2.3**	**1.7**	**2.6**	**2.5**	**1.1**	**.6**	**.6**	**2.2**	**1.0**	**2%**
13	*17141*	*-1.6*	*20.2*	*15.8*	*15.1*	*19.6*	*19.2*	*14.2*	*9.2*	*19.7*	*11.6*	*19.2*	*18.6*	*15.7*	*13.6*	*13.2*	*17.7*	*19.4*	*13.6*	*13.5*	*13.6*	*72%*
14	*4797*	*.4*	*19.8*	*16.9*	*15.7*	*19.0*	*18.4*	*14.4*	*11.3*	*19.8*	*13.8*	*18.8*	*18.0*	*15.9*	*14.1*	*14.0*	*17.2*	*19.0*	*14.6*	*14.5*	*14.5*	*76%*
15	*11301*	*-.9*	*19.7*	*18.4*	*17.2*	*18.9*	*19.0*	*16.6*	*15.7*	*19.7*	*14.8*	*19.3*	*19.3*	*17.1*	*14.0*	*14.8*	*18.0*	*19.3*	*17.0*	*15.2*	*16.1*	*84%*
16	*11312*	*-5.2*	*20.3*	*19.0*	*17.1*	*19.1*	*19.0*	*15.5*	*15.1*	*21.0*	*15.3*	*19.5*	*19.4*	*15.8*	*13.7*	*16.5*	*18.0*	*19.7*	*16.7*	*15.3*	*16.0*	*85%*
17	*10274*	*-7.2*	*21.2*	*19.7*	*18.0*	*20.3*	*19.9*	*17.6*	*16.0*	*21.9*	*14.1*	*19.5*	*19.3*	*17.3*	*13.6*	*14.9*	*18.7*	*20.4*	*17.8*	*15.0*	*16.4*	*86%*
18	*6568*	*-2.6*	*21.1*	*18.3*	*16.3*	*19.8*	*19.1*	*15.5*	*11.0*	*21.0*	*14.0*	*19.0*	*19.1*	*17.4*	*13.8*	*13.3*	*18.2*	*19.9*	*15.3*	*14.6*	*15.0*	*78%*
Exhaust Fan @ 0.32 ACH																						
19	9313	-2.4	21.4	15.8	14.7	19.4	18.8	13.3	6.2	23.8	11.1	20.8	20.3	17.0	13.3	11.5	18.5	20.8	14.6	13.2	13.9	70%
20	7583	.3	21.0	14.2	14.5	20.0	19.3	14.1	7.1	23.5	10.4	21.0	20.7	17.7	14.0	12.4	18.8	20.9	14.3	13.6	13.9	66%
21	7891	2.0	20.9	16.4	14.9	19.1	18.4	14.2	9.0	24.0	13.0	20.8	20.3	17.6	14.3	14.1	18.5	20.6	15.2	14.8	15.0	70%
22	7450	-.6	20.4	15.3	14.4	18.3	17.8	13.7	7.6	23.3	11.6	20.4	20.1	17.3	13.7	13.8	18.5	20.1	14.5	14.1	14.3	72%
23	5349	-2.0	20.6	16.1	14.5	18.1	17.9	13.3	6.6	23.0	11.2	20.5	20.1	17.7	13.8	12.1	18.5	20.0	14.6	13.7	14.2	73%
24	1191	-3.2	20.8	14.8	13.9	17.7	17.8	13.1	5.1	23.4	9.9	20.8	20.3	19.5	13.1	10.7	18.6	20.1	13.9	13.3	13.6	72%
25	7603	-.5	21.0	14.6	15.1	18.5	18.5	14.3	7.1	23.5	10.6	21.2	20.8	18.0	14.4	12.8	19.1	20.6	14.7	14.0	14.3	70%
26	7138	-15.4	20.9	15.5	12.4	17.5	16.3	8.7	1.0	23.8	8.5	20.4	20.1	13.6	11.6	7.7	18.4	19.8	12.2	10.4	11.3	76%
27	1109	-14.3	20.6	10.7	11.2	18.0	17.4	10.6	-.4	23.2	5.6	20.6	20.4	14.7	9.8	7.7	18.7	20.0	10.8	9.5	10.1	71%
28	6766	-16.7	20.5	13.4	9.6	18.4	17.1	9.5	1.4	23.2	6.7	20.4	20.1	13.1	7.9	10.7	18.4	20.0	10.8	9.6	10.2	73%
AVG	**6139**	**-5.3**	**20.8**	**14.7**	**13.5**	**18.5**	**17.9**	**12.5**	**5.1**	**23.5**	**9.9**	**20.7**	**20.3**	**16.6**	**12.6**	**11.4**	**18.6**	**20.3**	**13.6**	**12.6**	**13.1**	**71%**
STD	**2807**	**7.2**	**.3**	**1.7**	**1.8**	**.8**	**.9**	**2.1**	**3.2**	**.3**	**2.3**	**.3**	**.3**	**2.1**	**2.2**	**2.2**	**.2**	**.4**	**1.6**	**2.0**	**1.8**	**3%**
29	6919	-27.0	21.7	15.4	10.4	17.2	15.7	7.3	.3	24.7	5.7	21.4	21.0	10.9	6.4	7.1	18.9	20.3	8.4	7.5	7.9	74%
30	1365	-29.0	21.8	18.0	15.0	18.8	18.4	14.1	8.9	24.6	6.3	21.6	21.4	12.0	8.8	10.8	19.4	21.1	14.0	9.5	11.7	81%
31	6562	-29.8	21.3	9.2	8.9	18.3	16.6	8.2	-4.8	24.6	1.3	21.1	20.8	10.0	4.5	8.2	18.5	20.5	5.4	6.0	5.7	71%

LEGEND

SE BED - southeast bedroom (master), second floor
#-S - indicates main or second floor and direction wall is facing
NW BED - northwest bedroom, second floor
FAM RM - family room, main floor, south side
LVG RM - living room, main floor, northeast
#-Avg Dyna - main or second floor average temperature of dynamic air on main and second floor
Avg Dyna - average of main and second floor
Avg Indoor - average indoor temperature
% Temper - the portion of the total indoor/outdoor temperature difference that the incoming dynamic air was warmed up to
STD - standard deviation

NOTE: Data in italics has not been used in calculations.

FEBRUARY: DAILY AVERAGED DYNAMIC AIR TEMPERATURES (°C)

FEB	SOLAR (KJ/m2)	OUT DOOR	SE BED ROOM	2-S DYNA	2-E DYNA	NW BED ROOM	NW BED FLOOR	2-N DYNA	2-W DYNA	FAM ROOM	1-S DYNA	LVG ROOM	LVG RM FLOOR	1-N DYNA	1-E DYNA	1-W DYNA	BSMT	Avg Indoor	2-Avg Dyna	1-Avg Dyna	Avg Dyna	% Temper
01	*3571*	*-26.1*	*21.7*	*11.2*	*15.1*	*19.1*	*17.9*	*15.8*	*10.3*	*24.4*	*2.0*	*21.8*	*21.4*	*13.3*	*9.7*	*11.6*	*19.1*	*21.1*	*13.1*	*9.2*	*11.1*	
02	*6361*	*-17.2*	*21.3*	*12.0*	*12.8*	*19.0*	*18.1*	*12.7*	*5.3*	*24.5*	*6.5*	*21.4*	*20.9*	*14.1*	*9.2*	*11.7*	*18.8*	*20.9*	*10.7*	*10.4*	*10.5*	
Exhaust Fan Off																						
03	3075	-1.1	22.7	19.9	20.1	20.8	20.7	18.5	17.2	25.4	14.3	22.6	21.8	18.9	15.8	16.5	19.5	22.3	18.9	16.4	17.7	
04	6476	-2.6	23.0	21.6	20.2	21.2	20.9	18.5	17.9	25.7	16.8	22.4	21.6	18.2	16.0	16.5	19.0	22.5	19.6	16.9	18.2	
05	5510	-1.8	21.2	19.0	18.5	19.2	19.3	17.5	16.1	23.9	13.6	21.0	20.4	17.5	14.9	16.1	18.6	20.8	17.8	15.5	16.7	
06	5690	-2.8	21.8	20.2	18.9	19.3	19.6	18.0	16.6	24.4	14.7	21.4	20.8	17.6	15.3	16.5	18.5	21.2	18.4	16.0	17.2	
07	8087	-4.4	20.8	19.5	17.7	18.0	18.0	16.4	15.0	23.9	14.8	20.3	19.8	15.7	14.1	16.0	17.7	20.1	17.2	15.2	16.2	
08	7120	-12.3	20.3	20.1	17.1	18.0	17.5	14.9	14.3	23.2	15.6	19.9	19.5	14.3	13.4	16.3	17.9	19.7	16.6	14.9	15.8	
09	4972	-14.0	19.9	16.7	16.3	18.2	18.1	16.4	14.3	22.9	8.9	20.0	19.7	14.9	12.2	15.4	18.1	19.8	15.9	12.9	14.4	
10	7059	-.8	20.9	18.9	17.5	19.0	18.7	16.6	14.7	23.9	14.8	20.8	20.1	15.5	15.1	16.3	18.0	20.6	16.9	15.4	16.2	
11	2285	-4.7	20.3	18.2	17.7	19.1	18.5	14.6	15.0	23.2	14.7	20.4	19.9	15.3	15.0	16.3	18.0	20.2	16.4	15.3	15.9	
12	11064	-24.0	20.3	20.2	16.3	17.8	16.7	9.8	12.8	23.8	13.9	19.9	19.6	10.3	12.0	13.3	18.1	19.7	14.8	12.4	13.6	
13	11834	-22.5	21.6	18.3	17.0	19.5	18.9	15.9	13.1	24.6	9.6	21.4	20.9	11.9	11.0	15.4	19.2	21.2	16.1	12.0	14.0	
14	7647	-17.6	22.3	17.1	17.7	19.9	19.9	17.6	14.2	24.5	10.0	22.3	21.9	13.6	12.8	16.2	19.9	21.8	16.7	13.2	14.9	
AVG	6735	-9.1	21.3	19.1	17.9	19.2	18.9	16.2	15.1	24.1	13.5	21.0	20.5	15.3	14.0	15.9	18.5	20.8	17.1	14.7	15.9	
STD	2806	8.6	1.0	1.4	1.3	1.1	1.3	2.4	1.6	.9	2.5	1.0	.9	2.6	1.7	.9	.7	1.0	1.4	1.6	1.4	
15	*4216*	*-22.7*	*22.2*	*18.9*	*13.2*	*21.2*	*20.5*	*15.3*	*8.4*	*24.0*	*8.4*	*21.9*	*21.7*	*13.3*	*8.1*	*15.4*	*19.6*	*21.9*	*14.0*	*11.3*	*12.6*	
16	*5308*	*-24.7*	*21.8*	*14.6*	*9.2*	*19.8*	*18.9*	*11.4*	*1.4*	*23.8*	*5.3*	*21.7*	*21.4*	*12.4*	*6.6*	*14.8*	*19.0*	*21.2*	*9.2*	*9.8*	*9.5*	*74%*
17	*11703*	*-24.1*	*20.9*	*10.4*	*11.4*	*18.6*	*17.4*	*10.9*	*-.2*	*23.4*	*5.8*	*20.6*	*20.1*	*10.5*	*7.0*	*12.6*	*17.8*	*20.2*	*8.1*	*9.0*	*8.6*	*74%*
Exhaust Fan @ 0.32 ACH																						
18	11696	-9.7	21.4	14.6	13.2	19.0	17.9	11.1	2.7	23.9	11.4	21.3	20.6	13.9	11.7	13.8	17.9	20.7	13.0	12.7	12.8	74%
19	7863	-.5	21.6	16.0	16.1	19.4	18.7	13.4	7.5	23.8	12.9	21.6	21.0	16.9	15.0	15.8	18.6	21.0	15.2	15.2	15.2	73%
20	6182	1.3	21.9	17.0	16.5	19.8	19.6	14.8	9.2	23.6	13.8	21.8	21.2	17.9	15.9	17.0	19.0	21.3	16.1	16.2	16.1	74%
21	6228	-1.7	21.7	16.7	16.1	19.8	19.3	14.5	7.9	23.6	13.2	21.8	21.3	17.4	15.6	20.2	19.1	21.3	15.8	16.6	16.2	78%
22	10030	5.4	22.4	19.8	17.5	21.2	20.2	15.7	11.5	24.2	17.1	22.2	21.4	18.2	16.7	17.5	18.7	21.9	17.7	17.4	17.5	73%
23	4285	-4.0	22.1	18.1	15.5	20.5	19.7	14.6	9.1	23.6	14.0	21.9	21.2	17.8	14.5	17.1	19.2	21.5	16.1	15.9	16.0	78%
24	5832	-6.9	21.6	12.0	15.1	19.6	19.5	14.6	7.6	23.3	8.8	21.8	21.1	16.9	13.3	16.9	19.1	21.2	13.9	14.0	13.9	74%
25	7847	1.5	21.8	17.4	15.9	19.3	18.8	13.9	8.5	23.7	14.4	21.8	21.1	17.4	15.6	17.6	18.8	21.1	15.7	16.3	16.0	74%
26	12112	-3.0	21.6	18.8	15.3	17.9	17.5	12.6	7.3	23.3	14.9	21.1	20.3	15.4	14.1	15.9	18.1	20.3	15.6	15.1	15.3	79%
27	12433	.5	21.4	17.4	15.4	18.4	18.1	13.4	7.3	21.4	14.4	21.2	20.4	15.0	14.3	16.1	18.2	20.2	15.4	15.0	15.2	75%
28	9652	6.1	21.2	17.3	16.2	18.0	18.2	15.1	10.0	23.1	14.6	21.3	20.5	17.6	15.7	16.6	18.4	20.4	16.2	16.1	16.2	70%
AVG	8560	-1.0	21.7	16.8	15.7	19.4	18.9	14.0	8.1	23.4	13.6	21.6	20.9	16.8	14.8	16.8	18.6	21.0	15.5	15.5	15.5	75%
STD	2804	4.8	.3	2.1	1.1	1.0	.9	1.3	2.2	.7	2.1	.3	.4	1.4	1.4	1.6	.4	.5	1.2	1.3	1.3	3%

LEGEND

SE BED	- southeast bedroom (master), second floor
#-S	- indicates main or second floor and direction wall is facing
NW BED	- northwest bedroom, second floor
FAM RM	- family room, main floor, south side
LVG RM	- living room, main floor, northeast main or second floor
#-Avg Dyna	- average temperature of dynamic air on main and second floor
Avg Dyna	- average of main and second floor
Avg Indoor	- average indoor temperature
% Temper	- the portion of the total indoor/outdoor temperature difference that the incoming dynamic air was warmed up to.
STD	- standard deviation

NOTE: Data in italics has not been used in calculations.

MARCH: DAILY AVERAGED DYNAMIC AIR TEMPERATURES (°C)

MAR	SOLAR (KJ/m2)	OUT DOOR	SE BED ROOM	2-S DYNA	2-E DYNA	NW BED ROOM	NW BED FLOOR	2-N DYNA	2-W DYNA	FAM ROOM	1-S DYNA	LVG ROOM	LVG RM FLOOR	1-N DYNA	1-E DYNA	1-W DYNA	BSMT	Avg Indoor	2-Avg Dyna	1-Avg Dyna	Avg Dyna	% Temper
01	12524	4.6	22.2	20.2	16.3	19.1	18.7	14.8	10.7	23.8	17.1	21.7	20.8	17.5	15.7	16.9	18.5	21.1	17.1	16.8	17.0	75%
02	11432	4.3	21.9	19.1	16.4	19.1	18.7	14.7	10.4	23.5	16.0	21.5	20.6	17.3	15.5	16.2	18.5	20.9	16.7	16.3	16.5	74%
03	12463	3.4	21.6	19.9	16.7	19.9	19.2	15.2	11.4	23.3	16.6	21.4	20.5	17.2	15.7	17.1	18.6	21.0	17.3	16.7	17.0	77%
04	12287	.4	21.6	19.9	15.9	19.3	18.8	14.5	9.8	22.9	15.6	21.0	20.1	16.5	14.7	16.3	18.3	20.6	16.8	15.8	16.3	79%
05	5775	-1.9	21.6	15.3	14.9	18.9	19.0	14.7	7.3	23.2	12.2	21.8	21.1	17.6	14.5	15.2	19.3	20.9	15.0	14.9	14.9	74%
06	10972	3.1	21.5	17.3	15.7	18.8	18.7	14.7	9.0	23.4	14.4	21.4	21.0	17.0	15.1	15.1	19.0	20.8	15.9	15.4	15.7	71%
07	6439	1.4	21.6	16.6	15.4	19.1	19.0	14.9	8.7	23.5	13.8	21.7	21.0	17.6	15.0	15.2	19.2	21.0	15.6	15.4	15.5	72%
08	4203	.8	21.7	16.9	15.6	19.0	18.8	14.2	8.4	23.5	13.9	21.8	21.1	17.7	15.4	17.9	19.4	21.0	15.6	16.2	15.9	75%
09	14294	-1.3	21.6	17.9	14.1	19.3	18.4	12.6	7.1	24.0	14.9	21.5	20.7	16.4	13.7	16.3	18.8	20.9	14.9	15.3	15.1	74%
10	9293	1.2	21.4	17.5	15.1	20.2	19.2	14.1	9.2	23.7	14.7	21.4	20.7	17.5	14.7	17.2	18.9	21.1	15.6	16.0	15.8	73%
11	3293	-3.7	21.5	17.5	14.6	19.8	18.4	12.2	7.2	23.4	12.9	21.5	21.0	17.7	15.1	16.8	19.4	20.9	14.8	15.6	15.2	77%
12	13112	-4.9	22.0	18.3	14.0	18.3	17.5	11.1	5.3	24.0	14.4	21.6	20.9	16.7	14.2	16.3	18.9	20.7	14.5	15.4	14.9	77%
13	14601	-.9	22.1	18.5	15.2	18.7	18.2	13.0	6.8	23.9	14.6	21.8	10.9	16.8	14.2	16.3	18.8	19.3	15.6	15.5	15.5	81%
14	10445	.3	22.3	19.7	16.0	19.0	18.6	13.4	8.2	24.2	15.9	21.9	21.1	16.8	14.8	17.0	18.9	21.2	16.4	16.1	16.2	76%
15	13736	4.0	22.4	20.7	16.4	19.3	18.6	13.9	9.8	24.1	17.0	22.0	21.1	17.5	15.8	17.8	19.0	21.3	17.0	17.0	17.0	75%
16	7310	2.8	21.7	18.2	15.9	20.0	19.1	15.0	9.8	23.5	14.8	21.7	21.1	18.2	15.9	16.1	19.4	21.2	16.4	16.3	16.3	74%
17	15966	.9	21.2	18.0	15.4	19.0		13.5	9.6	23.7	16.2	21.1		16.8	15.4	15.6		21.2	15.6	16.0	15.8	73%
18	15406	3.9	21.2	17.6	16.3	19.2		13.9	10.1	23.7	15.7	21.0		17.0	15.5	17.3		21.3	15.9	16.4	16.2	71%
19	10877	6.9	21.9	19.9	17.0	19.6		15.3	11.9	23.4	16.6	21.4		19.4	16.7	17.6		21.6	17.4	17.6	17.5	72%
20	6449	-4.9	21.5	17.0	13.4	18.3		13.2	7.2	22.9	12.6	21.1		16.6	13.3	16.9		21.0	14.5	14.9	14.7	76%
21	12666	-9.6	21.0	15.8	12.9	17.8		9.4	2.1	23.1	10.8	20.9		14.5	13.6	15.6		20.7	12.7	13.6	13.2	75%
22	17913	-11.9	20.8	16.6	11.3	17.2		7.2	.3	23.1	10.3	20.6		13.6	11.8	13.3		20.4	11.7	12.3	12.0	74%
23	19171	-7.1	21.3	16.5	12.5	18.0		10.9	2.7	23.2	11.4	20.8		16.3	11.8	14.1		20.8	13.3	13.4	13.3	73%
24	17741	-1.3	21.4	17.1	13.9	18.7		12.2	5.9	23.2	13.1	20.8		18.8	13.6	15.0		21.0	14.4	15.1	14.8	72%
25	16805	.4	20.7	18.0	14.4	17.8		12.3	7.5	22.7	14.2	20.2		14.9	13.8	15.0		20.4	14.9	14.5	14.7	72%
26	14686	3.4	21.0	18.4	15.4	18.8		13.3	9.2	22.7	14.9	20.6		16.0	14.9	15.8		20.8	15.7	15.4	15.6	70%
27	10575	6.3	21.2	20.5	16.3	19.7		14.8	12.0	22.8	17.3	20.3		17.2	16.0	16.6		21.0	17.2	16.8	17.0	73%
28	16042	7.3	21.6	19.8	16.4	18.8		15.2	11.6	23.0	16.6	21.0		17.5	16.0	17.1		21.1	17.1	16.8	17.0	70%
29	15034	9.2	21.7	19.9	16.9	19.6		16.1	12.7	23.2	17.2	21.0		17.8	16.6	17.3		21.4	17.6	17.2	17.4	68%
AVG	12121	.6	21.6	18.2	15.2	19.0	18.7	13.5	8.3	23.4	14.7	21.3	20.2	17.0	14.8	16.2	18.9	20.9	15.6	15.7	15.6	74%
STD	4196	4.9	.4	1.5	1.4	.7	.4	1.9	3.0	.4	1.9	.5	2.5	1.2	1.2	1.1	.3	.4	1.4	1.2	1.3	3%

LEGEND

SE BED - southeast bedroom (master), second floor

2-S - indicates main or second floor and direction wall is facing

NW BED - northwest bedroom, second floor

FAM RM - family room, main floor, south side

LVG RM - living room, main floor, northeast main or second floor

2-Avg Dyna - average temperature of dynamic air on main and second floor

Avg Dyna - average of main and second floor

Avg Indoor - average indoor temperature

% Temper - the portion of the total indoor/outdoor temperature difference that the incoming dynamic air was warmed up to.

STD - standard deviation

NOTE: Data in italics has not been used in calculations.

APPENDIX E

AVERAGE TEMPERATURE DIFFERENTIAL ACROSS DYNAMIC WALL

DECEMBER: AVERAGE TEMPERATURE DIFFERENCE ACROSS DYNAMIC WALL (°C)

DEC	SOLAR (KJ/m^2)	OUT DOOR	Avg Indoor	2-S DYNA	Temp Diff	2-E DYNA	Temp Diff	2-N DYNA	Temp Diff	2-W DYNA	Temp Diff	1-S DYNA	Temp Diff	1-E DYNA	Temp Diff	1-N DYNA	Temp Diff	1-W DYNA	Temp Diff	2-Avg Diff	1-Avg Diff
Exhaust Fan @ 0.32 ACH																					
07	1936	-4.9	21.2	13.5	7.7	16.7	4.5	15.0	6.2	5.7	15.5	10.1	11.1	13.4	7.8	16.0	5.2	16.5	4.7	6.1	7.2
08	1843	-5.4	21.2	13.6	7.6	17.1	4.1	14.6	6.6	5.7	15.5	10.9	10.3	14.0	7.2	16.3	4.9	16.6	4.6	6.1	6.8
09	2451	-15.0	21.7	11.6	10.1	15.1	6.6	11.0	10.7	-.2	21.9	7.8	13.9	12.1	9.6	13.6	8.1	15.6	6.1	9.1	9.4
10	3857	-19.1	21.3	8.7	12.6	12.8	8.5	8.7	12.6	-4.8	26.1	5.1	16.2	8.8	12.5	11.7	9.6	14.0	7.3	11.2	11.4
11	1763	-5.4	21.8	10.6	11.2	17.4	4.4	12.1	9.7	2.5	19.3	8.6	13.2	12.9	8.9	15.3	6.5	15.7	6.1	8.4	8.7
12	3049	-1.5	19.7	15.5	4.2	16.9	2.8	13.2	6.5	6.1	13.6	12.9	6.8	15.2	4.5	16.3	3.4	16.9	2.8	4.5	4.4
13	1769	-.6	21.8	15.4	6.4	18.7	3.1	15.7	6.1	8.3	13.5	12.7	9.1	16.3	5.5	17.4	4.4	17.6	4.2	5.2	5.8
14	778	-2.5	21.6	12.4	9.2	17.9	3.7	14.6	7.0	6.8	14.8	10.5	11.1	14.9	6.7	16.6	5.0	17.3	4.3	6.6	6.8
15	1131	-5.3	21.8	14.6	7.2	17.6	4.2	14.0	7.8	6.7	15.1	11.8	10.0	15.1	6.7	16.1	5.7	17.0	4.8	6.4	6.8
AVG	2064	-6.6	21.3	12.9	8.5	16.7	4.7	13.2	8.1	4.1	17.3	10.0	11.3	13.6	7.7	15.5	5.9	16.4	5.0	7.1	7.5
STD	942	6.3	.7	2.3	2.6	1.8	1.8	2.2	2.3	4.2	4.3	2.5	2.8	2.2	2.4	1.8	1.9	1.1	1.3	2.1	2.1

LEGEND

#-S Dyna	- indicates dynamic air temperature on a specific wall, on the main or second floor
Temp Diff	- temperature difference between indoor dynamic air
#-Avg Diff	- average temperature difference on main or second floor
STD	- standard deviation

JANUARY: AVERAGE TEMPERATURE DIFFERENCE ACROSS DYNAMIC WALL (°C)

JAN	SOLAR (KJ/m2)	OUT DOOR	Avg Indoor	2-S DYNA	Temp Diff	2-E DYNA	Temp Diff	2-N DYNA	Temp Diff	2-W DYNA	Temp Diff	1-S DYNA	Temp Diff	1-E DYNA	Temp Diff	1-N DYNA	Temp Diff	1-W DYNA	Temp Diff	2-Avg Diff	1-Avg Diff
Exhaust Fan @ 0.23 ACH																					
03	12600	-13.2	21.1	12.6	8.5	16.2	4.9	12.4	8.7	3.4	17.7	9.0	12.1	12.3	8.8	14.1	7.0	15.9	5.2	7.3	8.3
04	10968	-13.7	21.1	10.7	10.4	15.7	5.4	12.8	8.3	1.6	19.5	7.6	13.5	12.2	8.9	14.2	6.9	15.7	5.4	8.1	8.7
05	12700	-7.4	21.3	10.8	10.5	17.8	3.5	13.8	7.5	3.9	17.4	8.5	12.8	13.7	7.6	15.3	6.0	16.2	5.1	7.1	7.8
06	13927	1.3	21.5	14.8	6.7	18.6	2.9	16.3	5.2	8.9	12.6	12.6	8.9	16.4	5.1	17.3	4.2	17.8	3.7	4.9	5.4
07	11239	.2	21.4	14.7	6.7	18.6	2.8	16.3	5.1	9.1	12.3	12.7	8.7	16.3	5.1	17.3	4.1	18.0	3.4	4.9	5.4
AVG	12287	-6.6	21.3	12.7	8.5	17.4	3.9	14.3	6.9	5.4	15.9	10.1	11.2	14.2	7.1	15.6	5.6	16.7	4.5	6.5	7.1
STD	1204	7.1	.2	2.0	1.9	1.4	1.2	1.9	1.7	3.4	3.3	2.4	2.2	2.1	1.9	1.6	1.4	1.1	.9	1.5	1.6
Exhaust Fan @ 0.28 ACH																					
09	8840	.3	21.3	15.8	5.5	19.9	1.4	17.3	4.0	12.8	8.5	13.2	8.1	16.5	4.8	17.3	4.0	17.5	3.8	3.6	5.2
10	5312	-1.7	21.1	19.1	2.0	20.7	.4	14.3	6.8	10.2	10.9	17.2	3.9	16.5	4.6	16.9	4.2	17.4	3.7	3.1	4.1
11	19732	-5.9	21.8	18.3	3.5	20.7	1.1	17.0	4.8	13.0	8.8	14.2	7.6	15.9	5.9	16.6	5.2	17.3	4.5	3.2	5.8
12	17777	-6.7	20.3	16.8	3.5	19.5	.8	17.6	2.7	14.9	5.4	10.7	9.6	11.1	9.2	13.6	6.7	12.5	7.8	2.4	8.3
AVG	12915	-3.5	21.1	17.5	3.6	20.2	.9	16.6	4.6	12.7	8.4	13.8	7.3	15.0	6.1	16.1	5.0	16.2	5.0	3.1	5.9
STD	6941	3.4	.6	1.5	1.4	.6	.4	1.5	1.7	1.9	2.3	2.7	2.4	2.6	2.1	1.7	1.2	2.5	1.9	.5	1.8
Exhaust Fan @ 0.32 ACH																					
19	9313	-2.4	20.8	15.8	5.0	14.7	6.1	13.3	7.5	6.2	14.6	11.1	9.7	13.3	7.5	17.0	3.8	11.5	9.3	6.2	7.5
20	7583	.3	20.9	14.2	6.7	14.5	6.4	14.1	6.8	7.1	13.8	10.4	10.5	14.0	6.9	17.7	3.2	12.4	8.5	6.7	7.3
21	7891	2.0	20.6	16.4	4.2	14.9	5.7	14.2	6.4	9.0	11.6	13.0	7.6	14.3	6.3	17.6	3.0	14.1	6.5	5.4	5.8
22	7450	-.6	20.1	15.3	4.8	14.4	5.7	13.7	6.4	7.6	12.5	11.6	8.5	13.7	6.4	17.3	2.8	13.8	6.3	5.6	6.0
23	5349	-2.0	20.0	16.1	3.9	14.5	5.5	13.3	6.7	6.6	13.4	11.2	8.8	13.8	6.2	17.7	2.3	12.1	7.9	5.4	6.3
24	1191	-3.2	20.1	14.8	5.3	13.9	6.2	13.1	7.0	5.1	15.0	9.9	10.2	13.1	7.0	19.5	.6	10.7	9.4	6.2	6.8
25	7603	-.5	20.6	14.6	6.0	15.1	5.5	14.3	6.3	7.1	13.5	10.6	10.0	14.4	6.2	18.0	2.6	12.8	7.8	5.9	6.6
26	7138	-15.4	19.8	15.5	4.3	12.4	7.4	8.7	11.1	1.0	18.8	8.5	11.3	11.6	8.2	13.6	6.2	7.7	12.1	7.6	9.5
27	1109	-14.3	20.0	10.7	9.3	11.2	8.8	10.6	9.4	-.4	20.4	5.6	14.4	9.8	10.2	14.7	5.3	7.7	12.3	9.2	10.6
28	6766	-16.7	20.0	13.4	6.6	9.6	10.4	9.5	10.5	1.4	18.6	6.7	13.3	7.9	12.1	13.1	6.9	10.7	9.3	9.1	10.4
AVG	6139	-5.3	20.3	14.7	5.6	13.5	6.8	12.5	7.8	5.1	15.2	9.9	10.4	12.6	7.7	16.6	3.7	11.4	8.9	6.7	7.7
STD	2807	7.2	.4	1.7	1.6	1.8	1.6	2.1	1.8	3.2	3.0	2.3	2.1	2.2	2.0	2.1	1.9	2.2	2.1	1.4	1.8

LEGEND

#-S Dvna	- indicates dvnamic air temperature on a specific wall, on the main or second floor
Temp Diff	- temperature difference between indoor dynamic air
#-Avg Diff	- average temperature difference on main or second floor
STD	- standard deviation

FEBRUARY: AVERAGE TEMPERATURE DIFFERENCE ACROSS DYNAMIC WALL (°C)

FEB	SOLAR (KJ/m2)	OUT DOOR	Avg Indoor	2-S DYNA	Temp Diff	2-E DYNA	Temp Diff	2-N DYNA	Temp Diff	2-W DYNA	Temp Diff	1-S DYNA	Temp Diff	1-E DYNA	Temp Diff	1-N DYNA	Temp Diff	1-W DYNA	Temp Diff	2-Avg Diff	1-Avg Diff
Exhaust Fan @ 0.32 ACH																					
18	11696	-9.7	20.7	14.6	6.1	13.2	7.5	11.1	9.6	2.7	18.0	11.4	9.3	11.7	9.0	13.9	6.8	13.8	6.9	7.7	8.0
19	7863	-.5	21.0	16.0	5.0	16.1	4.9	13.4	7.6	7.5	13.5	12.9	8.1	15.0	6.0	16.9	4.1	15.8	5.2	5.9	5.9
20	6182	1.3	21.3	17.0	4.3	16.5	4.8	14.8	6.5	9.2	12.1	13.8	7.5	15.9	5.4	17.9	3.4	17.0	4.3	5.2	5.2
21	6228	-1.7	21.3	16.7	4.6	16.1	5.2	14.5	6.8	7.9	13.4	13.2	8.1	15.6	5.7	17.4	3.9	20.2	1.1	5.5	4.7
22	10030	5.4	21.9	19.8	2.1	17.5	4.4	15.7	6.2	11.5	10.4	17.1	4.8	16.7	5.2	18.2	3.7	17.5	4.4	4.3	4.6
23	4285	-4.0	21.5	18.1	3.4	15.5	6.0	14.6	6.9	9.1	12.4	14.0	7.5	14.5	7.0	17.8	3.7	17.1	4.4	5.4	5.7
24	5832	-6.9	21.2	12.0	9.2	15.1	6.1	14.6	6.6	7.6	13.6	8.8	12.4	13.3	7.9	16.9	4.3	16.9	4.3	7.3	7.2
25	7847	1.5	21.1	17.4	3.7	15.9	5.2	13.9	7.2	8.5	12.6	14.4	6.7	15.6	5.5	17.4	3.7	17.6	3.5	5.3	4.8
26	12112	-3.0	20.3	18.8	1.5	15.3	5.0	12.6	7.7	7.3	13.0	14.9	5.4	14.1	6.2	15.4	4.9	15.9	4.4	4.7	5.2
27	12433	.5	20.2	17.4	2.8	15.4	4.8	13.4	6.8	7.3	12.9	14.4	5.8	14.3	5.9	15.0	5.2	16.1	4.1	4.8	5.2
28	9652	6.1	20.4	17.3	3.1	16.2	4.2	15.1	5.3	10.0	10.4	14.6	5.8	15.7	4.7	17.6	2.8	16.6	3.8	4.2	4.3
AVG	8560	-1.0	21.0	16.8	4.1	15.7	5.3	14.0	7.0	8.1	12.9	13.6	7.4	14.8	6.2	16.8	4.2	16.8	4.2	5.5	5.5
STD	2804	4.8	.5	2.1	2.1	1.1	.9	1.3	1.1	2.2	2.0	2.1	2.1	1.4	1.3	1.4	1.1	1.6	1.4	1.1	1.1

LEGEND

#-S Dyna	- indicates dynamic air temperature on a specific wall, on the main or second floor
Temp Diff	- temperature difference between indoor dynamic air
#-Avg Diff	- average temperature difference on main or second floor
STD	- standard deviation

MARCH: AVERAGE TEMPERATURE DIFFERENCE ACROSS DYNAMIC WALL (°C)

MAR	SOLAR (KJ/m2)	OUT DOOR	Avg Indoor	2-S DYNA	Temp Diff	2-E DYNA	Temp Diff	2-N DYNA	Temp Diff	2-W DYNA	Temp Diff	1-S DYNA	Temp Diff	1-E DYNA	Temp Diff	1-N DYNA	Temp Diff	1-W DYNA	Temp Diff	2-Avg Diff	1-Avg Diff
01	12524	4.6	21.1	20.2	.9	16.3	4.8	14.8	6.3	10.7	10.4	17.1	4.0	15.7	5.4	17.5	3.6	16.9	4.2	4.0	4.3
02	11432	4.3	20.9	19.1	1.8	16.4	4.5	14.7	6.2	10.4	10.5	16.0	4.9	15.5	5.4	17.3	3.6	16.2	4.7	4.1	4.6
03	12463	3.4	21.0	19.9	1.1	16.7	4.3	15.2	5.8	11.4	9.6	16.6	4.4	15.7	5.3	17.2	3.8	17.1	3.9	3.7	4.3
04	12287	.4	20.6	19.9	.7	15.9	4.7	14.5	6.1	9.8	10.8	15.6	5.0	14.7	5.9	16.5	4.1	16.3	4.3	3.9	4.8
05	5775	-1.9	20.9	15.3	5.6	14.9	6.0	14.7	6.2	7.3	13.6	12.2	8.7	14.5	6.4	17.6	3.3	15.2	5.7	6.0	6.1
06	10972	3.1	20.8	17.3	3.5	15.7	5.1	14.7	6.1	9.0	11.8	14.4	6.4	15.1	5.7	17.0	3.8	15.1	5.7	4.9	5.4
07	6439	1.4	21.0	16.6	4.4	15.4	5.6	14.9	6.1	8.7	12.3	13.8	7.2	15.0	6.0	17.6	3.4	15.2	5.8	5.3	5.6
08	4203	.8	21.0	16.9	4.1	15.6	5.4	14.2	6.8	8.4	12.6	13.9	7.1	15.4	5.6	17.7	3.3	17.9	3.1	5.4	4.8
09	14294	-1.3	20.9	17.9	3.0	14.1	6.8	12.6	8.3	7.1	13.8	14.9	6.0	13.7	7.2	16.4	4.5	16.3	4.6	6.1	5.6
10	9293	1.2	21.1	17.5	3.6	15.1	6.0	14.1	7.0	9.2	11.9	14.7	6.4	14.7	6.4	17.5	3.6	17.2	3.9	5.5	5.1
11	3293	-3.7	20.9	17.5	3.4	14.6	6.3	12.2	8.7	7.2	13.7	12.9	8.0	15.1	5.8	17.7	3.2	16.8	4.1	6.2	5.3
12	13112	-4.9	20.7	18.3	2.4	14.0	6.7	11.1	9.6	5.3	15.4	14.4	6.3	14.2	6.5	16.7	4.0	16.3	4.4	6.3	5.3
13	14601	-.9	19.3	18.5	.8	15.2	4.1	13.0	6.3	6.8	12.5	14.6	4.7	14.2	5.1	16.8	2.5	16.3	3.0	3.7	3.8
14	10445	.3	21.2	19.7	1.5	16.0	5.2	13.4	7.8	8.2	13.0	15.9	5.3	14.8	6.4	16.8	4.4	17.0	4.2	4.8	5.1
15	13736	4.0	21.3	20.7	.6	16.4	4.9	13.9	7.4	9.8	11.5	17.0	4.3	15.8	5.5	17.5	3.8	17.8	3.5	4.3	4.2
16	7310	2.8	21.2	18.2	3.0	15.9	5.3	15.0	6.2	9.8	11.4	14.8	6.4	15.9	5.3	18.2	3.0	16.1	5.1	4.8	4.9
17	15966	.9	21.2	18.0	3.2	15.4	5.8	13.5	7.7	9.6	11.6	16.2	5.0	15.4	5.8	16.8	4.4	15.6	5.6	5.6	5.2
18	15406	3.9	21.3	17.6	3.7	16.3	5.0	13.9	7.4	10.1	11.2	15.7	5.6	15.5	5.8	17.0	4.3	17.3	4.0	5.3	4.9
19	10877	6.9	21.6	19.9	1.7	17.0	4.6	15.3	6.3	11.9	9.7	16.6	5.0	16.7	4.9	19.4	2.2	17.6	4.0	4.2	4.0
20	6449	-4.9	21.0	17.0	4.0	13.4	7.6	13.2	7.8	7.2	13.8	12.6	8.4	13.3	7.7	16.6	4.4	16.9	4.1	6.4	6.1
21	12666	-9.6	20.7	15.8	4.9	12.9	7.8	9.4	11.3	2.1	18.6	10.8	9.9	13.6	7.1	14.5	6.2	15.6	5.1	8.0	7.1
22	17913	-11.9	20.4	16.6	3.8	11.3	9.1	7.2	13.2	.3	20.1	10.3	10.1	11.8	8.6	13.6	6.8	13.3	7.1	8.7	8.2
23	19171	-7.1	20.8	16.5	4.3	12.5	8.3	10.9	9.9	2.7	18.1	11.4	9.4	11.8	9.0	16.3	4.5	14.1	6.7	7.5	7.4
24	17741	-1.3	21.0	17.1	3.9	13.9	7.1	12.2	8.8	5.9	15.1	13.1	7.9	13.6	7.4	18.8	2.2	15.0	6.0	6.6	5.9
25	16805	.4	20.4	18.0	2.4	14.4	6.0	12.3	8.1	7.5	12.9	14.2	6.2	13.8	6.6	14.9	5.5	15.0	5.4	5.5	5.9
26	14686	3.4	20.8	18.4	2.4	15.4	5.4	13.3	7.5	9.2	11.6	14.9	5.9	14.9	5.9	16.0	4.8	15.8	5.0	5.1	5.4
27	10575	6.3	21.0	20.5	.5	16.3	4.7	14.8	6.2	12.0	9.0	17.3	3.7	16.0	5.0	17.2	3.8	16.6	4.4	3.8	4.2
28	16042	7.3	21.1	19.8	1.3	16.4	4.7	15.2	5.9	11.6	9.5	16.6	4.5	16.0	5.1	17.5	3.6	17.1	4.0	4.0	4.3
29	15034	9.2	21.4	19.9	1.5	16.9	4.5	16.1	5.3	12.7	8.7	17.2	4.2	16.6	4.8	17.8	3.6	17.3	4.1	3.7	4.2
AVG	12121	.6	20.9	18.2	2.7	15.2	5.7	13.5	7.5	8.3	12.6	14.7	6.2	14.8	6.1	17.0	3.9	16.2	4.7	5.3	5.2
STD	4196	4.9	.4	1.5	1.5	1.4	1.3	1.9	1.8	3.0	2.8	1.9	1.8	1.2	1.1	1.2	1.0	1.1	1.0	1.3	1.0

LEGEND

#-S Dyna	- indicates dynamic air temperature on a specific wall, on the main or second floor
Temp Diff	- temperature difference between indoor dynamic air
#-Avg Diff	- average temperature difference on main or second floor
STD	- standard deviation main and second floor

APPENDIX F

COST COMPARISON FOR DEMONSTRATION HOUSE AND R-2000 STANDARD HOUSE

APPENDIX F

COST COMPARISONS FOR DEMONSTRATION HOUSE AND R-2000 STANDARD HOUSE

F.1 INCREMENTAL COST OF THE DEMONSTRATION HOUSE

In order to determine the incremental cost of the demonstration house, the construction standards currently in use by the majority of Alberta builders were used as the basis for comparison. The standards are summarized as follows:

Envelope	
Walls above grade	R20 (fibreglass batts in 2 x 6 walls) plywood or OSB sheathing
Ceilings	R40 (blown cellufibre) [as compared to the code requirement for R34]
Basement walls	R12 (fibreglass batts in 2 x 4 frost walls) [as compared to the code requirement for R12 to 2 feet below grade]
Airtightness	No standard (but latest studies indicate approximately 3.0 ACH at 50 Pa)
Mechanical Systems	
Heating	Naturally aspirated gas furnace
Hot water	Naturally aspirated gas
Mechanical ventilation	Individual bath and kitchen stove hood fans

The incremental costs of the dynamic wall demonstration house are as follows:

Glasclad Sheathing	
Glasclad sheathing vs. 3/8" spruce plywood	1150.00
- SBPO taped vs. black building paper	
- Washer head nails	
Framing materials	500.00
- 2 x 2 spruce starter strip below main floor Glasclad	
- 2 x 4 backers around window and door openings	
- 2 x 12 spruce backing for belly bands	
- 2 x 4/6 backers for exterior trim boards	
- 2 x 6 backers for roof-wall interfaces	
- 1 x 4 spruce bracing	
Labour	500.00
- Various details to ensure proper backing for windows, doors, decorative boards, flashings	

- Various details to install the exterior SBPO air barrier	

Total: Glasclad Sheathing	$2150.00
2 x 4 Framing vs. 2 x 6 Framing	<700.00>
Window Jamb Extensions	200.00
Airtightness of the Interior (drywall and lumber) Air Barrier	
Materials: gaskets, expandable foam	100.00
Labour: (gasketing, foaming miscellaneous penetrations)	500.00

Total: Airtightness of the Interior Air Barrier	$600.00
Mechanical Systems	
Closed combustion "Lennox Pulse" furnace	1400.00
Induced draft hot water tank	350.00
Central exhaust system	445.00
Fresh air intake fan	200.00

Total: Mechanical Systems	$2395.00
Finishing Details	
Drywall holes for dynamic air; installation of the baseboards after finishing the house rather than during the normal finishing procedure	300.00

SUMMARY	
Glasclad Sheathing	2150.00
2 x 4 vs. 2 x 6 Framing	<700.00>
Window Jamb Extensions	200.00
Airtightness of the Interior Air Barrier	600.00
Mechanical Systems	2395.00
Venting Baseboard Detail	300.00

TOTAL	$4945.00
	========

F.2 INCREMENTAL COSTS OF TYPICAL R-2000 CONFIGURATIONS

Costs have been calculated for the following configurations, which are all practical alternative designs that a builder might use to meet the R-2000 requirements. The costs are incremental to the "standard" Alberta house described in Section 3.1.

Configuration #1

Airtightness of the interior air barrier	$600.00
Mechanical systems	
Closed combustion "Lennox Pulse" furnace	1400.00
Induced draft hot water tank	350.00
Heat recovery ventilator	1610.00
Triple glazed windows	500.00
Total	$4460.00

Configuration #2

Total as in Configuration #1	$4460.00
Double glazed windows vs. triple glazed	<500.00>
Insulation: Ceiling (R40 to R50); Frost (R12 to R20)	300.00
Total	$4260.00

Configuration #3

Total as in Configuration #1	$4460.00
Insulation: Ceiling (R40 to R50); Frost (R12 to R20)	300.00
Induced draft furnace vs. Lennox Pulse	<800.00>
Total	$3960.00

These totals are similar to detailed cost estimates obtained from a recently completed study sponsored by Alberta Municipal Affairs, *Assessment of Cost-Effectiveness of R-2000 Energy Measures in the Prairies* (Howell Mayhew Engineering Inc. 1989). This study indicates that R-2000 homeowners in Alberta have purchased homes similar in size to the demonstration house. With a unit incremental cost of $2.46 per square foot, the demonstration house built to R-2000 standards would have an incremental cost of approximately $5781 (2350 sq. ft. x $2.46). When optimized through the use of HOT-2000, the unit incremental cost was reduced to $1.84 per square foot. Using this unit cost, the demonstration house would have incremental costs of approximately $4324 (2350 sq. ft. x $1.84). The incremental costs estimated for the dynamic wall house upgraded to meet the R-2000 standards and optimized using HOT-2000 are consistent with the costs experienced by R-2000 builders in Alberta, i.e., \$3960 to \$4460 as compared to \$4324.

F.3 INCREMENTAL COSTS OF BUILDING THE DEMONSTRATION HOUSE TO MEET R-2000 REQUIREMENTS

A difficulty in configuring the demonstration house to meet the R-2000 program requirements results from the question of the ventilation heat recovery potential. A realistic range for this potential heat recovery is 25% to 50%. The upper end is based on Dr. Timusk's determination that 60% of the ventilation air entering his demonstration house was dynamic air and that this air was being heated to 84% of the temperature differential between outside and inside air (0.60 x 0.84 = 56.4%). The lower end is based on the measurements of dynamic air flow in the demonstration house. Approximately 25% of the total ventilation rate was measured at the holes drilled through the drywall into the dynamic wall cavities. This appears to provide an overall efficiency of heat recovery below 25% (0.25 x 0.84 = 23.5%); however, it is assumed that the total air flow measured through the dynamic holes is an indication of the minimum amount of dynamic air since part of the air not entering the house through the dynamic air holes is also subject to the energy transfer effects predicted by the Dynamic Wall Theory.

The other factor not taken into consideration is the effect of solar radiation, which has been shown in the Timusk studies to raise the dynamic air temperatures to well above indoor air temperatures. Consequently, the energy consumption of the house has been estimated using values at both ends of the range, but the calculations of true value is believed to be near the middle.

The incremental costs of building the demonstration house to meet the R-2000 standard are as follows:

(1) To Meet the R-2000 Energy Budget (assuming 50% heat recovery efficiency in ventilation air heat recovery)

Total demonstration house costs (Section 4.7.1)	$4245.00
Triple glazed windows	500.00
Insulation: Ceiling (R40 to R50); Frost (R12 to R20)	300.00

Total	$5045.00
	=======

(2) To Meet the R-2000 Energy Budget (assuming 25% heat recovery efficiency in ventilation air heat recovery)

Total demonstration house costs (Section 4.7.1)	$4245.00
Insulation: Flat ceiling (R50 to R60); Cathedral (R40)	140.00
Walls: 2 x 6 (vs. 2 x 4) (with 1-1/2" Glasclad)	700.00
Frost walls: R20 (vs. R12)	160.00

Total	$5245.00
	=======

As noted in Section 3.1.4, a 4-foot-wide section of wall was installed with fibreboard sheathing and Tyvek instead of Glasclad. This is an attractive alternative because of its lower cost relative to the significant cost of Glasclad.

Using HOT-2000, the following configuration was determined to meet the R-2000 program requirements (assuming a 50% ventilation heat recovery efficiency):

Total for (1) above	$5045.00
Deletion of Glasclad sheathing	<2150.00>
2 x 6 (vs. 2 x 4), fibreboard, and taped Tyvek	1200.00

Total	$4095.00
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APPENDIX G

POTENTIAL ALTERNATIVE SHEATHING CONFIGURATIONS FOR THE DYNAMIC WALL SYSTEM

APPENDIX G

POTENTIAL ALTERNATIVE SHEATHING CONFIGURATIONS FOR THE DYNAMIC WALL SYSTEM

One of the highest cost components is the Glasclad sheathing. If Glasclad were available in a one-inch thickness, the cost of the house would be lower by $450 in material costs. All the costs for extra labour and backing materials would remain the same. If it were possible to eliminate the requirement for this material altogether, the incremental cost would be reduced by about $2150.

If the dynamic wall concept were effective with the Tyvek only, without the compressed fibreglass board, then a number of envelope configurations would be possible:

(1) No Sheathing; Cross Bracing and Tyvek Only

If the Glasclad could be eliminated and a more conventional 2 x 6 wall used with no exterior sheathing material, the exterior would be wrapped only with the SBPO house wrap and clad with siding. However, a number of problems would have to be dealt with:

(a) Backing for Siding Materials. Without some rigid sheathing material for backing, there might be problems with the installation of vinyl siding, which is commonly used for cladding in Alberta. The deformation and "unhooking" problems caused by temperature changes might be aggravated. In addition, some special backing details are needed to provide solid material to nail into.

These problems would not exist if aluminum siding were used. However the incremental cost for aluminum siding (compared to vinyl) is estimated to be $1200. Wooden siding could be used, but as with aluminum, costs would be higher.

(b) Backing for Stucco. The question of the permeability of the stucco-Tyvek combination remains. But, in addition, there might be problems applying stucco over wire and Tyvek without the support provided by a solid sheathing material, e.g. stucco that is applied too thickly in the mid cavity area and results in some durability problems.

(c) The Potential Elimination of Some Wall Areas from Dynamic Action. The Glasclad sheathing as used in the current design would appear to provide another advantage not previously discussed: the Glasclad may provide a pathway for air to travel freely throughout the envelope, only interrupted by corners and other areas which require solid wood backers (such as the belly band area).

This pathway might be important in some areas, for example, the kitchen, where cupboards might prevent the use of a section of exterior wall for ventilation air intake. The free movement of air through the Glasclad would mean that adjacent dynamic wall cavities could draw air from these otherwise non-dynamic wall cavity areas.

(d) The Elimination of a Consistent "Flow Straightening" Section in the Wall Cross-Section. The assumption to date has been that the Glasclad provides a higher density material (than fibreglass batt insulation), encouraging air flow normal to the wall surface (at least for the 1-1/2" thickness of the Glasclad) before the air makes its way towards the opening in the drywall.

The consistency of the Glasclad material is also thought to preclude the possibility of air being channelled directly to the drywall holes without picking up heat because of voids and other deficiencies in the fibreglass batt insulation.

(2) 2 x 6 Walls Sheathed with Diagonally Nailed 1 x 4s or Strips of 3/8" Plywood

If 3/8" plywood strips were used, the reduction in the quantity of 3/8" exterior plywood used would offset the extra costs associated with ripping 4' x 8' plywood sheets to make 3" wide strips and the additional costs of applying these strips.

With this wall system, there might be short circuiting of the dynamic wall action due to the ability of cold air to flow towards the dynamic wall opening through the channels created by the strips (between the Tyvek and the fibreglass batts), rather than to move slowly through the Glasclad and fibreglass batts. The plywood strips might eliminate, or at least severely restrict, the free passage of air through the Tyvek.

(3) 2 x 6 Walls with Impermeable Sheathings Containing Holes Similar to Pegboards

This might be a reasonable solution to the problem of backing and support for such exterior finishes as vinyl siding, but would not allow the free flow of exterior air across dynamic wall cavities. In addition, the surface area for the free flow of air through the Tyvek would be significantly restricted unless the holes were made much larger than they are in normal pegboard.

(4) 2 x 6 Walls with Alternative Sheathings such as Fibreboard (Buffalo-board)

Fibreboard provides the most promising alternative to Glasclad. According to a study done by CMHC, fibreboard in combination with Tyvek has an air permeability very similar to that of Glasclad. The differences in performance would appear in the following areas: a slightly higher wall insulation level (lower in the fibreboard, but higher within the 2 x 6 cavity as compared to a 2 x 4), a shorter distance in which the air might travel normal to the wall surface, and lower potential for mitigation against voids in the batt insulation.

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